PANDALID SHRIMPS IN A TIDEWATER-GLACIER FJORD, AIALIK BAY, ALASKA

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PANDALID SHRIMPS IN A TIDEWATER-GLACIER FJORD, AIALIK BAY, ALASKA

A

THESIS

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ABSTRACT

Vertical migration and food habits of pandalid shrimps in Aialik Bay, a tidewater-glacier fjord, were related to suspended sediment load and available food resources. Suspended sediments from subglacial streams resulted in Secchi depths of 0.4-1.0 m near the glacier, increasing with distance from the glacier to 1.0-5.0 m near the sill. A large proportion of the *Pandalus borealis* and *P. goniurus* populations responded to reduced light in the upper bay by remaining in midwater throughout the day and night. Shrimp food resources, represented by zooplankton and benthos, were reduced in abundance and diversity near the glacier as compared to the region near the sill. Shrimps fed more intensively near or at the bottom than in midwater. The most common items in stomachs of *P. borealis* were unidentifiable organic matter (84.5%), sediment (83.1%), crustacean fragments (60.9%), identified crustaceans (16.9%), mollusks (16.3%), foraminiferans (15.1%), and plant material (10.0%).

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INTRODUCTION

The presence and activities of marine invertebrates, mammals, and birds in tidewater-glacier fjords have attracted the attention of scientists for many years (Hartley and Fisher 1936, Stott 1936, Hartley and Dunbar 1938, Streveler and Paige 1971, Hale and Wright 1979). Pandalid shrimps are abundant in the fjords and large numbers of seals are commonly observed near tidewater glaciers. Kittiwakes, fulmars, gulls and other seabirds feed amidst the calving ice at the glacier face. Meltwater from glacial streams carries a high suspended sediment load (Hoskin et al. 1976) which presumably reduces the amount of primary production in the water column. Thus, the large number of organisms present and the apparent high productivity observed near tidewater glaciers are unexpected there. Although shrimps have been fished, and harbor seals and whales observed in tidewater-glacier fjords, little information is available concerning the abundance of marine invertebrates and the effects of the glacier and the high suspended sediment load on marine organisms.

In 1979-1981 the National Park Service sponsored a study of the impact of human activities on harbor seals (*Phoca vitulina*) and Glaucous-winged Gulls (*Larus glaucesens*) in Aialik Bay, Alaska, a tidewater-glacier fjord in Kenai Fjords National Park (Figure 1). The biology of marine invertebrates and marine processes were not a part of the study. In order to gain some insights about the effect of the glacier and the high suspended load on the dominant invertebrates in Aialik Bay, an investigation of some aspects of the biology of pandalid

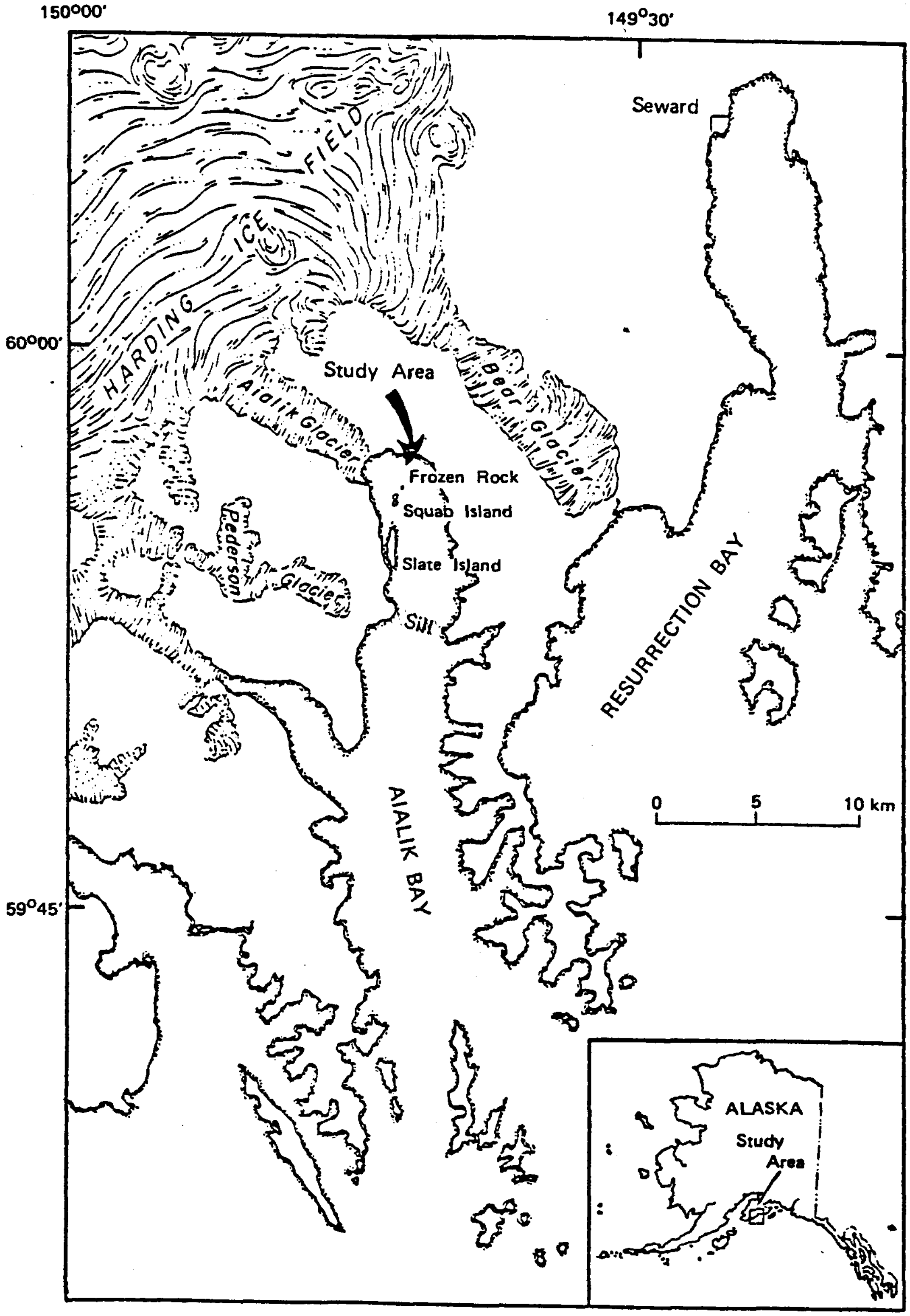

Figure 1. Location of the study area, Aialik Bay, Alaska.

shrimps and relevent physical and biological parameters was initiated in December 1979 in conjunction with the National Park Service study. Information on the biology of pandalid shrimps would also be useful for management of a fishery for these organisms in glacial fjords.

Objectives

The objectives of the study were to:

1. Characterize the suspended sediment load, the organic content of the bottom sediments, and the zooplanktonic and benthic organisms of Aialik Bay.
2. Determine the distribution of shrimps relative to the glacier and to substrate characteristics.
3. Determine the vertical distribution and diel migration patterns of shrimps relative to the suspended sediment load.
4. Determine the food resources used by the shrimps.

Glacial Fjords

Narrow, steep-sided, glacially carved coastal inlets are called tidewater-glacier fjords if the glacier is still present and terminates below sea level, and turbid outwash fjords if the glacier terminates on land. Glacial fjords typically have a sill which may restrict circulation of water. Tidewater glaciers discharge icebergs and subglacial meltwater directly into marine waters, whereas meltwater from turbid outwash glaciers flows across glacial sediment deposits before entering the marine system. The suspended sediment load is generally lower in a tidewater-glacier fjord, although both fjord types are characterized by a plume of sediment-laden water.

The periodic renewal of deep water in a fjordic basin from source water outside the sill prevents the development or continuation of anoxic conditions in Alaskan fjords. Muench and Heggie (1976) suggest that for shallow-silled fjords in Alaska, such as Aialik Bay (10 m sill depth), source water reaches a density maximum at sill depth during late winter, and that deepwater renewal in the inner basin occurs annually during March and April. Matthews and Quinlan (1975) found that the maximum density difference across the sill (69 m) in Muir Inlet, a tidewater-glacier fjord in southeastern Alaska, occurred in February, thus, the best conditions for deepwater renewal were during the winter. In contrast, deepwater renewal occurs during summer in deep-silled fjords such as Resurrection Bay (185 m sill depth). Maximum density water is present at deep sills when reduced summer winds result in relaxation of downwelling along the Alaskan coast (Royer 1975). A fjord with a sill depth near 150 m, such as Port Valdez, may have deepwater renewal throughout the year because there is little density variation of outside water at 150 m. Renewal of inside water at mid-depths could occur whenever water of greater density is present at sill depth outside, as compared to inside, the basin (David Nebert, personal communication, Matthews and Quinlan 1975). It is suggested that outside water of greater density is carried over the sill and mixes during flood tide, and is retained within the basin while surface water flows out at ebb tide.

Water circulation may be enhanced by the presence of a tidewater glacier in a fjord. Greisman (1979) suggests that upwelling at a submerged glacier face is driven by melting of ice in saltwater. The proposed circulation process for Muir Inlet includes melting of the glacier face at depth (Matthews and Quinlan 1975). The effect of melting at the glacier face in Muir Inlet was masked during periods of high runoff, but showed as a cooling and freshening effect during the winter. Hartley and Dunbar (1938) investigated the water with a high sediment load (the "brown zone") adjacent to a tidewater glacier in Greenland and found high salinities at the water surface. They suggest that upwelling occurred at the submerged face of the glacier. High salinity surface water was associated with the presence of planktonic Crustacea as well as seabirds feeding at the surface of the "brown zone". A similar study by Stott (1936) at a West Spitsbergen tidewater glacier contradicts the findings of Hartley and Dunbar (1938). He found low surface salinity resulting from a glacial drainage stream, and rejects the possibility of upwelling. In addition, he suggests that euphausiids were responding to low salinity by rising towards the surface.

Enhancement of nutrients within the euphotic zone may occur by processes related to the presence of a glacier. Upwelling at the submerged face of a tidewater glacier (Greisman 1979) could mix nutrients into surface water. Apollonio (1973) suggests that glacial activity contributes nutrients to the marine system. He found an increase in nitrates and silicates in an Arctic tidewater-glacier fjord as compared to a non-glacial fjord. Terrestrial debris, and excretory products and feces from marine mammals and birds are also potential nutrient sources in glacial fjords. Meltwater in glacial streams is low in dissolved organic carbon (Loder and Hood 1972); thus, glacial ice does not contribute much organic nutrients.

The effects of an increase in nutrients on primary production in glacial fjords may be counteracted by reduction of light in the water column by suspended sediment loads from glacial meltwater and streams. Primary production in two Alaskan glacial fjords was reported to be restricted by high sediment loads (Loder and Hood 1972, Goering et al. 1973). When the euphotic zone was less than one meter in depth during summer in Port Valdez, Alaska, there was a 20-fold reduction in primary production relative to late spring primary production; low salinity also restricted primary production in surface water (Goering et al. 1973). A high sediment load apparently also restricts the biomass, abundance and number of benthic taxa in glacial fjords. In Queen Inlet (a turbid outwash fjord in Glacier Bay, Alaska), suspended sediment loads exceeded 1 g/liter and sediment accumulation was estimated to exceed 1 m/yr at the head and 0.4 m/yr at the mouth of the fjord (Hoskin and Burrell 1972). Two fragments of unidentified organisms were collected from the bottom at the fjord head and 12 taxa were collected in small numbers at 8.3 km down the fjord (Hoskin et al. 1976). A comparison of three fjords in Prince William Sound showed higher abundance, biomass, and number of benthic taxa in a tidewater-glacier fjord than a turbid outwash or non-glacial fjord (Hoskin 1977). Only at the sill, 8 km from the head, in the sediment-laden outwash fjord did the biomass and number of species exceed those of the tidewater-glacier fjord.

Crustaceans brought near the surface of the water adjacent to tidewater glaciers by upwelling (Hartley and Dunbar 1938), response to low salinity (Stott 1936), or turbulence of stream outflow and falling ice (Hale and Wright 1979), are important food items for other organisms in the fjord. Euphausiids were the principal food items found in stomachs of fulmars and kittiwakes feeding in a glacier-front "brown zone" in Spitsbergen (Hartley and Fisher 1936). The presence of humpback whales in Glacier Bay has been related to the opportunity for feeding on euphausiids and shrimps (Hale and Wright 1979). Although harbor seals are primarily attracted to tidewater-glacier fjords by the icebergs available as haul out sites (Murphy and Hoover 1981), some feeding on shrimps may occur there as well (Hartley and Fisher 1936, Imler and Sarber 1947, Burns and Gol'tsev, in press). The large numbers of crustaceans, mammals, and seabirds in tidewater-glacier fjords are a contrast to the reduced primary production and low abundance of benthic organisms found there.

Pandalid Shrimps

Distribution

Five species of pandalid shrimps are common in Alaskan waters (McLean et al. 1977); the pink shrimp, *Pandalus borealis*; the humpback shrimp, *Pandalus goniurus*; the coon-stripe shrimp, *Pandalus hypsinotus*; the spot shrimp or prawn, *Pandalus platyceros*; and the side-stripe shrimp, *Pandalopsis dispar*. *Pandalus borealis* occurs in coastal regions from the Chukchi and Bering Seas to the Columbia River, Washington and

Hokkaido, Japan in the Pacific. In the Atlantic and Arctic Oceans it ranges from Cape Cod to Greenland, to as far north as Spitsbergen and Franz Josef Land. *Pandalus borealis* is commonly associated with soft, muddy sediments at 50-650 m (Allen 1959, Butler 1980). The pink shrimp is tolerant of salinities of less than 30 o/oo (Butler 1964) and occurs in high densities at salinities as low as 32.29 o/oo (Ivanov 1970). The distributions of the four other species of pandalids are similar to that of *P. borealis* in the Pacific. However, the range of *P. platyceros* extends as far south as San Diego and *Pandalopsis dispar* is found only on the eastern side of the Pacific. *Pandalus platyceros* is more common in rocky areas than soft muddy bottoms (Butler 1980). All of the other species are associated with muddy substrata.

Life history

All of the species of pandalid shrimps are protandric hermaphrodites. *Pandalus borealis* first develops as a male at one and a half years of age. After one or two years as a male, the shrimp undergoes a transition phase in which external male characteristics are lost and the gonads develop into ovaries (Butler 1964, Rasmussen 1967). In the southern part of their range, part of the population may follow a different pattern of maturation. Up to fifty percent of *P. borealis* may develop directly as a female or undergo the transition from male to female by one and a half years of age (Butler 1980). Following the sex transition, the shrimp remains a female for the balance of its life. Life spans vary from three to five years in different thermal regimes (Ivanov 1964, Butler 1980). The life cycles of the other species of pandalids follow the same general pattern as *P. borealis*, although there are variations in age at maturity, age of sexual transition, and total life span.

Pandalus borealis usually spawns in September or October. Eggs are carried through the winter until March or April when larvae are released. The duration of the ovigerous period varies from five months in the more southern regions such as British Columbia and Norway, to nine months in Arctic regions such as Spitsbergen, West Greenland, and Jan-Mayen. The ovigerous period is extended by earlier spawning and/or delay of larval release (Rasmussen 1967). In addition, timing of development of larvae and sexual transition of the shrimp varies with latitude. Slow growth and maturation occur in water of low temperature (Rasmussen 1967); e.g., slow-growing populations found in isolated cold waters of a fjordic basin may be at the same latitude as a faster growing population in the open sea.

Vertical migration

Evidence of vertical migration of pandalid shrimps is reported by several authors. Incidental capture of *Pandalus jordani* (Anon. 1956, Schaefers and Powell 1958) and *P. borealis* (Blacker 1957, Rathjen and Fahlen 1962) during night-time midwater trawling for fishes occurred up to 171 m above the bottom. Smaller catches of *P. jordani* from bottom trawls taken at night compared with catches taken during the day also suggest that some of the shrimp leave the bottom during darkness (Schaefers and Johnson 1957, Tegelberg and Smith 1957, Beardsley 1973). Studies of *P. borealis* in Alaskan waters, *P. goniurus* in Russian waters, and *P. jordani* off the coast of Oregon verify that shrimps undergo a diel vertical migration in these waters also (Barr 1970, Pearcy 1970, 1972, Barsukov and Ivanov 1979). Although *P. jordani* does not occur in Aialik Bay, information on its migratory behavior is useful as a basis of comparison with the pandalids that are present there.

The general pattern for diel migration in *P. borealis*, *P. jordani*, and *P. goniurus* is to rise off the bottom at dusk, reaching the highest levels (within 20 m of the surface) by midnight, and returning to the bottom shortly after sunrise. The shrimps remain close to the bottom throughout the daylight period, except on days when light intensity is reduced by cloud cover (Beardsley 1973). Barsukov and Ivanov (1979) found no evidence that smaller *P. goniurus* migrate to higher levels than larger shrimp, but Pearcy (1970, 1972) and Barr (1970) suggest that there is a greater tendency for smaller, male *P. jordani* and *P. borealis* to migrate off the bottom.

Rothlisberg and Pearcy (1976) found that vertical migratory behavior begins while *P. jordani* is in the late larval phase, just prior to the final molt to the juvenile stage when recruitment to the bottom occurs. The early juvenile shrimp are abundant on the bottom during the day, and are absent in the upper 50 m. During the night juveniles are absent from the bottom, and appear throughout the water column as high as the upper 50 m. A response to light was suggested by Barr (1970) who captured *P. borealis* in pots in the upper 23 m of the water column for a longer period of time during long winter nights than during summer nights. The effect of light is also demonstrated by the increase of above-bottom catches of *P. jordani* on cloudy days (Beardsley 1973).

Pearcy (1970) relates shrimp migrations to feeding opportunities and avoidance of predators. Other authors report evidence for vertical migration but make few comments on the significance of this behavior (Blacker 1957, Tegelberg and Smith 1957, Schaefers and Powell 1958, Barr 1970, Dahlstrom 1970, Beardsley 1973, Rothlisberg and Pearcy 1976, Barsukov and Ivanov 1979).

Food habits

Stomach contents of pandalid shrimps were examined from several locations: *Pandalus montagui* from estuaries in England (Mistakidis 1957, Allen 1963); *P. borealis*, *P. hypsinotus*, *P. goniurus* and *Pandalopsis dispar* collected in Cook Inlet (Crow 1977, Rice et al. 1980); *P. borealis* from Kodiak Island (Feder and Jewett 1981); *P. jordani* collected off the Oregon coast (Pearcy 1970). Based on the available literature, pandalid shrimps are either carnivorous bottom feeders (*P. montagui*, *P. borealis*, *P. hypsinotus*, *P. goniurus*, *P. platyceros*, *P. danae*, *Pandalopsis dispar*), vertically-migrating zooplankton feeders (*P. borealis*, *P. goniurus*, *P. jordani*), planktonic filter feeders (*P. borealis*), detritus (*P. borealis*, *P. goniurus*, *P. hypsinotus*), diatom and algal feeders (*P. montagui*, *P. borealis*, *P. hypsinotus*, *P. jordani*, *Pandalopsis dispar*) or any combination of these feeding strategies (additional food data found in Berkeley 1929, Turpaeva 1953, Horsted and Smidt 1956, Barr 1970, Butler 1970, Dahlstrom 1970, Barsukov and Ivanov 1979). Pandalid shrimps, especially species which leave the bottom, are apparently able to utilize a broad spectrum of benthic and pelagic food resources.

The Study Area

Aialik Bay is located southwest of Resurrection Bay, Alaska (Figure 1). It is a shallow-silled (6-10 m) fjord with a stable tidewater glacier, which flows from the Harding ice field, at its head. Steep slopes of Sitka spruce (*Picea sitchensis*) and alder (*Alnus crispa*) grade into sparsely vegetated talus and bare rock at higher elevations (Murphy and Hoover 1981). Two vegetated islands (Squab and Slate Islands) and an unvegetated rock (Frozen Rock), exposed only at mid and low tides, are located between the glacier and the sill. The area between the glacier and the sill is referred to as the "upper bay" in this thesis (Figure 1). The maximum depth of the basin inside the sill is about 190 m, while the water depth at the glacier face ranges from 0 to 60 m (Figure 2). The depth of the fjord outside the sill is about 240-300 m (Post 1980, personal observations).

The center of the glacier is grounded on rock above sea level, while the glacier face on either side drops to below sea level. The rock is exposed to about 30 m above sea level during late summer following the period of most active glacial calving. A subglacial stream emerges on the north side of the rock, and a second meltwater stream flows into the bay from the southern edge of the glacier. These two streams comprise the major freshwater input into the upper bay. Minor contributions come from a few small streams and icebergs melting directly into the water. Yearly precipitation in the area averages 160 cm, with the maximum occurring in the late summer and fall and minimum in June (U.S. Department of Commerce 1977). Two other glaciers flow

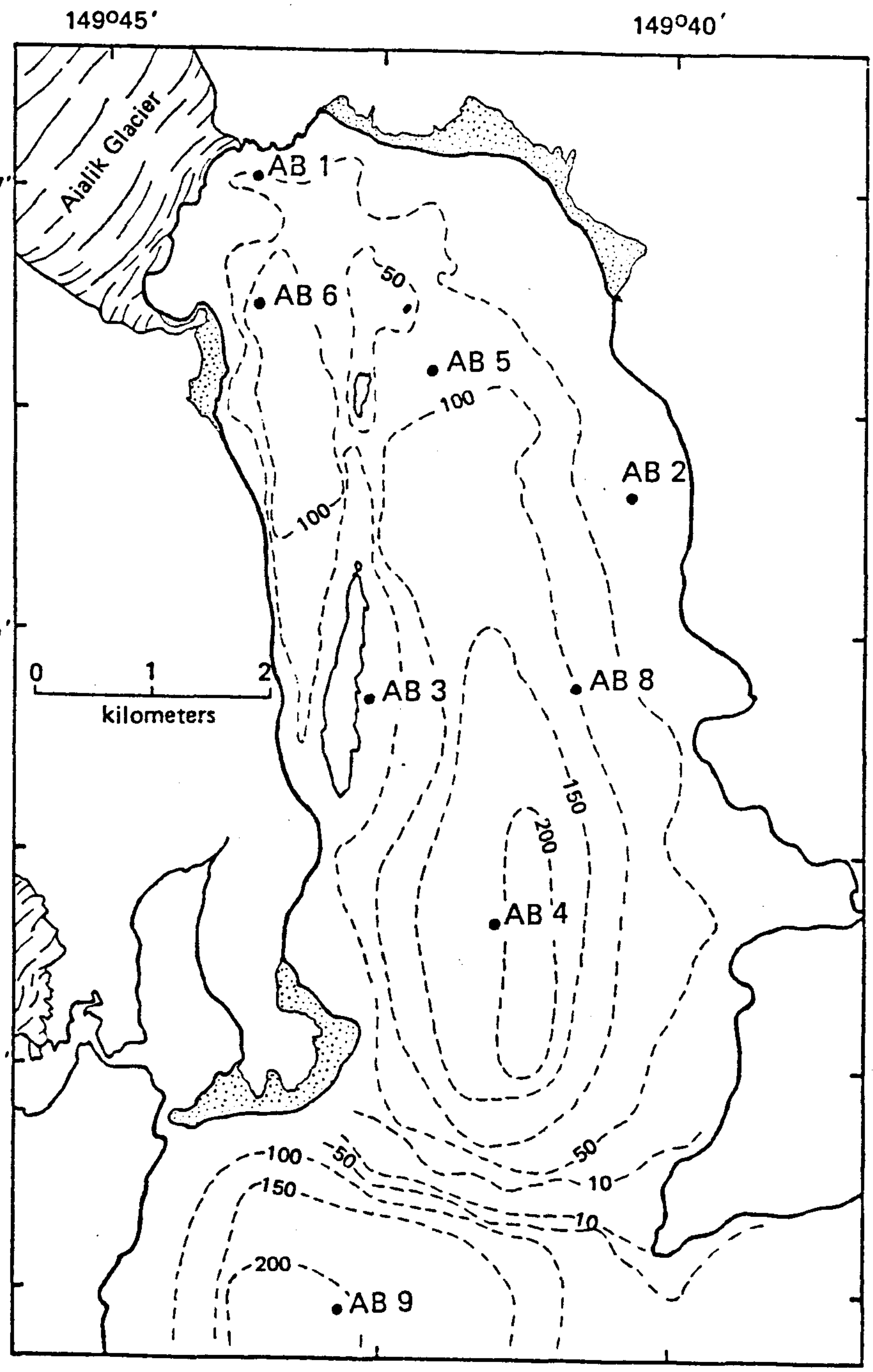

Figure 2. Bathymetric and station map of Aialik Bay.

into Aialik Bay from the Harding ice field (Figure 1). Both glaciers enter the bay outside the sill, and have little effect on the upper bay environment.

METHODS

General

Data were collected in Aialik Bay (Figure 1) from the R/V *Acona* in December 1979 and the R/V *Alpha Helix* in June and December 1980 and November 1981. Additional collections were made in June and July 1980 and May 21-June 12, 1981 from a field camp established for a National Park Service Kenai Fjords project. Summaries of all stations occupied and collections reported in this thesis are shown in Tables 1 and 2. A transect consisting of five stations was established for hydrographic and biological sampling (Figure 2 and Table 1). Occasional collections were made at additional stations in the upper bay. The location and description of stations and physical features referred to in the text are included in Table 1. Sampling was accomplished in the shallow, uncharted glacier-front region from the R/V *Acona* in December 1979 and from a five meter skiff at all other times.

Hydrographic measurements

Water temperature, salinity, oxygen content, and depth were measured with a Niel-Brown Mark III CTD system from the R/V *Acona* and R/V *Alpha Helix* at stations AB 1, AB 4, AB 5, AB 8, and AB 9. Water samples and temperature data were collected during the summer of 1980 by Nansen bottle casts with reversing thermometers. Salinity was measured with a 6230 Bissett Berman-Plessey salinometer. Data collected during previous cruises in Aialik Bay was obtained from the Institute of Marine Science data bank in Fairbanks, Alaska.

Table 1. Location and description of stations and physical features in Aialik Bay, Alaska, referred to in the text.

Station or feature	Longitude (West)	Latitute (North)	Distance from glacier	Water depth	Bottom type
Aialik glacier face (center)	149°44.3'	59°56.7'	0 km	0-60 m	soft gray mud
AB 1	149°43.7'	59°57.2'	0.2 km	38-75 m	soft gray mud
*AB 6	149°43.7'	59°56.5'	1 km	107 m	soft gray, mud
Squab Island	149°42.8'	59°56.1'	1.6 km	-	rock
Frozen Rock	149°42.4'	59°56.5'	1.6 km	-	rock
*AB 5	149°42.0'	59°56.2'	3 km	80-88 m	soft gray mud, much gravel
AB 2	149°40.3'	59°55.5'	4.5 km	40 m	soft gray mud, lit-tle gra-vel, leaves, and organic debris
AB 3	149°42.4'	59°54.7'	4.5 km	140 m	soft gray mud, leaves and debris
*AB 8	149°40.6'	59°54.6'	6 km	148-177 m	firm gray mud,little organic debris and gravel
*AB 4	149°41.5'	59°53.7'	8 km	192 m	firm gray mud, organic debris, lit-tle gravel
Sill (center)	149°42.0'	59°52.5'	10 km	10 m	-
*AB 9	149°42.5'	59°51.5'	12 km	242-260 m	firm mud and sand, occa-sional rocks

*Transect stations

Table 2. The station location and type of collections made in Aialik Bay and reported in this thesis.

Type of collection	December 1979 R/V *Acona*	June 1980 R/V *Alpha Helix*	June-July 1980 field camp	December 1980 R/V *Alpha Helix*	May-June 1981 field camp	November 1981 R/V *Alpha Helix*
Hydrographic	AB 1,4 (CTD)	AB 4,5,9 (CTD)	AB 4,6,9 (Nansen)	AB 4,5,9 (CTD)	-	AB 4,5,8,9 (CTD)
Suspended load	AB 1,2 (light meter)	-	AB 1,4,6,8,9 (Secchi)	-	AB 1,4,6,8 (Secchi) AB 4,5,6 (SS)	-
Sediment organics	-	-	-	AB 4 (core)	-	AB 4,5,6,8,9 (VVG)
Zooplankton: vertical tows	AB 1,4 (1 m,202μ)	AB 4 (1 m,202μ)	AB 1,4,6,8,9 (½ m,216μ)	AB 4,5,9 (1 m,202μ)	-	-
Isaac-Kidd midwater trawl				AB 4		
Benthos: grab and dredge	AB 1,2,4 (VVG, 1 each)	-	-	AB 4,5,9 (VVG, 5 each)		AB 4,8,9 (VVG,5) AB 5 (VVG,6) AB 6 (PD,EK,1 each)
Otter trawl	AB 3-4 (1)	AB 5-8 (1)	-	AB 4-5 (2)	-	-
Shrimp pots	-	-	AB 4,6 and more	-	AB 6	-

SS=suspended sediment
VVG=van Veen grab

PD=pipe dredge
EK=Ekman dredge

Suspended sediment load

Light intensity in the water column was measured at two stations (AB 1, AB 2) in December 1979 with a Li-Cor model L1-185A quantum meter with a L1-192S underwater quantum sensor. Turbidity was measured by Secchi disc at several stations during the summers of 1980 and 1981. Secchi disc depths were measured opportunistically along with other collections at all stages of the tidal cycle. Secchi disc depths were converted to an estimate of the depth of the euphotic zone (defined as the depth at which light intensity is 1% of the solar radiation reaching the water surface). An extinction coefficient (k) was determined from the Secchi disc depth (D_s) by the equation

$$k = 1.7/D_s$$

(Poole and Atkins 1929). The light intensity (I_d) at any depth (d) is found by the equation

$$I_d = I_o e^{-kd}$$

where I_o is the incoming light intensity (Parsons et al. 1977). Thus, for the 1% light level, d is the depth of the euphotic zone, and

$$d = 4.6/k = 4.6 (D_s)/1.7.$$

Water samples were collected during the summer of 1981 for suspended sediment load determinations. The water samples were filtered through Millepore filters, dried at 60°C, and the filters cooled in a desiccator and weighed. The filters were dried again, cooled, and re-weighed. Since a final freshwater rinse was inadvertently omitted after samples were filtered, suspended sediment load is reported as relative values.

Organic content of the sediment

A sediment sample was taken from the surface of one van Veen grab at each station occupied in November 1981; all samples were immediately frozen. In addition, a sediment core was obtained at station AB 4 in December 1980 using a Benthos gravity corer. In the laboratory, thawed sediment samples were dried for 24 hours at 60-80°C, pulverized, and analyzed for carbon and nitrogen with a Perkin-Elmer 240C Elemental Analyzer. A separate set of acid-treated samples were analyzed to insure that carbonate values were insignificant relative to total carbon.

Collection and analysis of zooplankton

Replicate vertical zooplankton net tows were taken at stations AB 1, AB 4, AB 6, AB 8, and AB 9. A one meter diameter net (202μ mesh) was used from the R/V *Acona* in December 1979 and the R/V *Alpha Helix* in June and December of 1980. A half meter diameter net (216μ mesh) was fished from a skiff using a small winch during the summer of 1980. All tows were raised at a constant rate of 1 m/s. Tows were taken from 3-5 m off the bottom to the surface from the R/V *Acona* and R/V *Alpha Helix*. Tows from the skiff were taken from standard depths of 150 m at AB 4, AB 8, and AB 9, and from 50 m at AB 1 and AB 6 to prevent dragging the net on the bottom when a fathometer was unavailable. Additional tows were made from three or four different depths at stations AB 4 and AB 6 to evaluate and compare the vertical distribution of zooplankton biomass. All samples were fixed in 5% formalin in seawater.

Pandalid shrimps collected with zooplankton samples were removed and used in the food-habit studies reported in this thesis. Six of the zooplankton samples were examined to determine species abundances. Large organisms (mysids, amphipods, euphausiids, and chaetognaths) were sorted, identified and counted. The remaining organisms were suspended in 1-2 liters of water and replicate subsamples of 5 ml removed by Stemple pipette. Each subsample was flushed into a Petri dish and examined with a Wild dissection scope. Organisms were sorted, identified to the lowest taxon possible, and counted. Concentrations were calculated as number of organisms per square meter (no./m^2) integrated over the entire water column.

Species richness was calculated for several zooplankton samples using Margalef's index (Brower and Zar 1977),

$$D_a = (s-1)/\ln N$$

where s = number of species and N = total number of individuals. The index increases in value as the number of species increases. An index which accounts for both the number of species and the evenness of occurrence of individuals within each species is Simpson's index (Brower and Zar 1977),

$$\lambda = \Sigma\, n_i\ (n_i - 1)/N(N - 1)$$

where n_i = number of individuals of ith species and N = total number of individuals. λ is the probability that two individuals taken at random from a community will belong to the same species, and is a measure of dominance. It varies from 0 (no individuals are of the same species) to 1.0 (all individuals are of the same species). The Shannon index (Brower and Zar 1977), which measures diversity is calculated as,

$$H' = -\Sigma\, p_i \log p_i$$

where $p_i = n_i/N$, n_i = number of individuals of ith species, and N = total number of individuals. The index is based on the uncertainty in predicting the identity of a randomly picked individual. The Shannon diversity index is appropriate for a random sample from a community of unknown size. The above indices were calculated for zooplankton samples from stations AB 1, AB 4, and AB 9.

Subsamples for biomass estimates were obtained by use of a plankton splitter (modified from a geological sand splitter as described in Cooney 1971). Each subsample was dried for 24 hours at 60°C, cooled in a desiccator, and weighed; the sample was dried for an additional 2-4 hours, cooled, and re-weighed. Biomass was calculated as grams dry weight per square meter (g/m^2) integrated over the entire water column.

The nonparametric Kruskal-Wallis test (Conover 1980, Dixon and Brown 1981, program 3S) was used to test the difference between stations in distribution of biomass of zooplankton collected in summer and winter. In this test, the biomass for each station and replicate is assigned a rank, and a rank sum, R_i, is calculated for each station (treatment). The test statistic,

$$T = 1/S^2 (\sum_{i=1}^{k} R_i^2/n_i - N(N+1)^2/4)$$

is calculated, where $S^2 = 1/(N-1)\ (\Sigma R(X_{ij}) - N(N+1)^2/4$, N = total number of samples, n_i = number of samples in ith treatment, and X_{ij} = rank of each sample. If T is larger than the χ^2 approximation with k-1 degrees of freedom, pairs of treatments (stations) are compared to determine which treatments differ by,

$$|R_i/n_i - R_j/n_j| > t_{1-\alpha/2} \; (S^2(N-1-T)/(N-k))^{\frac{1}{2}} (1/n_i + 1/n_j)^{\frac{1}{2}}$$

where $t_{1-\alpha/2}$ is from the Student's t distribution.

Euphausiids and pelagic shrimps were collected after dark in December 1980 with a 1.8 m Isaacs-Kidd trawl with 1/4 inch mesh from a midwater aggregation of plankton located with a Ross 200A echo sounder. Organisms were fixed in 10% formalin buffered with hexamethylenetetramine (Mueller 1977), and returned to the laboratory for identification. Pandalid shrimps collected in the midwater trawl were used in the food-habit studies reported in this thesis.

Van Veen grab collections

Benthic organisms were collected from the R/V *Acona* and R/V *Alpha Helix* with a 0.1 m² van Veen grab weighted with 60 kg of lead. Single grabs were collected at each of three stations (AB 1, AB 2, AB 4) in December 1979. Three stations (AB 4, AB 5, AB 9) were sampled in December 1980 and four stations (AB 4, AB 5, AB 8, AB 9) in November 1981. At least five replicate grabs were taken at each station. In addition, station AB 6 was sampled from a skiff in November 1981 with a 0.055 m² Ekman dredge and 15 cm diameter pipe dredge. Samples were washed through a 1.0 mm² mesh screen on ship board. The organisms and debris retained on the screen were fixed in 10% hexamethylenetetramine buffered formalin.

In the laboratory, animals were identified to the lowest possible taxon and counted. Counts were based on the number of identifiable anterior ends. Pieces which had no anterior end were grouped under "fragments" of the lowest taxon to which they could be classified. Specimens were blotted dry, and wet weights determined. All taxa were counted, inclusive of infauna and mobile epifauna. The counts and weights of benthic marine organisms were determined for each station, and the number of individuals of each taxa per square meter (no./m^2) calculated.[1] Species richness, the Simpson dominance index, and the Shannon diversity index were calculated for each station at each sampling period.

Similarity between stations were examined with the Sørenson coefficient (Brower and Zar 1977),

$$CC = 2c/(s_1 + s_2)$$

where s_1 = number of taxa at station 1, s_2 = number of taxa at station 2, and c = number of taxa present at both stations. Values for the Sørenson coefficient range from 0 (no taxa in common) to 1.0 (all taxa in common). Sørenson coefficients were calculated for selected pairs of stations.

The number of benthic taxa was tabulated into geometric classes (class I = 1 individual/m^2, class II = 2-3, class III = 4-7, class IV = 8-15, class V = 16-31, etc.) according to the method of Gray and Pearson

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[1] Computer program MSCLOUT written by G. Matheke is on file at the Institute of Marine Science, Fairbanks, AK 99701.

(1982). The data were plotted as the number of individuals per taxon on the abscissaa and the number of taxa in each geometric class on the ordinate.

Trawl collections

Epibenthic organisms were collected by trawl from the R/V *Acona* and R/V *Alpha Helix* in December 1979, June 1980, and December 1980. An otter trawl with a four-meter mouth opening and a cod end lining of 6 mm^2 mesh was used. Trawl depths varied from 80 to 192 m due to steepness of the bottom (see Figure 2). All trawls were towed at approximately 3 knots with the trawl on the bottom for 10-15 minutes.

All animals were counted and identified on shipboard. Samples of the pandalid shrimps were fixed in 10% buffered hexamethylenetetramine, and returned to the laboratory for use in the food-habit studies reported in this thesis.

Shrimp pot collections

Benthic and pelagic collections of pandalid shrimps were made during the summers of 1980 and 1981 with baited shrimp pots. The pots were constructed of a 1/2 inch polyethylene tubing frame covered with 1/4 inch mesh nylon (McBride and Barr 1967). A two-pound coffee can filled with cement was used as an anchor, and five pots were attached with halibut clips to a 1/2 inch braided nylon line between the anchor and a surface buoy. The pots were evenly spaced from a depth of 3 m to the bottom. A subsurface buoy was attached to the line between the two highest pots to keep the array vertical during low water in the tidal cycle (Barr and McBride 1967). The pots were baited with fish (usually salmon or herring) contained in a perforated plastic carton suspended within the pot. Bait was reused for several sets since it continued to attract numerous shrimps. Following the method of Barr (1970) the vertical array of pots was set for 3-8 hour intervals over a 24-hour period. The time intervals were morning (6-10 am), mid-day (10 am-2 pm), afternoon (2-6 pm), evening (6-10 pm), and night (10 pm-6 am). The night interval included all hours of darkness, from sundown to sunrise. Between each interval the pots were pulled up into the boat, emptied, and reset in the same location. Time-series collections were made at stations AB 4 and AB 6. Longer sets were also made at several locations.

All shrimps were counted and identified; a subsample of 25-30 shrimps was retained from large catches and all specimens retained from catches of less than 25. The shrimps from each pot were placed in separate Whirlpak bags, fixed in 10% hexamethylenetetramine buffered formalin, and returned to the laboratory for use in the food-habit studies reported in this thesis.

The difference in numbers of *Pandalus borealis* captured at five depths during three time-series pot sets at station AB 6 was analyzed by a nonparametric two-way ANOVA on ranked catch values (Conover and Iman 1981, Dixon and Brown 1981, program 2V). The difference in numbers of *P. borealis* captured during a single time-series collection at station AB 4 was analyzed by the same method, but without testing for interaction between depth and time. The difference in size between *P.borealis* captured at five depths in the water column was tested by a

Student's t-test. The tests were repeated for *P. goniurus* captured at five depths. The same test was used to test the difference in size of *P. borealis* between stations AB 6 and AB 4.

Analysis of stomach contents of shrimps

Shrimps to be examined for stomach contents were rinsed and blotted dry, weighed, measured (carapace length=posterior edge of eye socket to mid-dorsal edge of carapace), and sexed. Sexing was based on external characteristics only (Butler 1980). Males had an obvious notch in the endopodite of the first pleopod, and an appendix masculina of approximately the same size as the appendix interna on the second endopodite. Transitional shrimps showed a change in shape of the first endopodite with the notch reduced to a residual extension off the side, and the appendix masculina was decreased in size. Females were those in which no notch remained, the endopodite was smoothly pointed and no trace of the appendix masculina was found (see Allen 1959 p.200 for illustrations of the changes with age and sexual transition).

Stomachs were dissected out of the body, opened, and assessed for percent fullness by volume. Qualitative estimates of total stomach contents (percent volume) were made according to the following scale: 1. nothing present (0%); 2. a trace to a small amount present (1-5%); 3. less than 1/4 but more than 5% full (15%); 4. about 1/4 full (25%); 5. less than 1/2 but more than 1/4 full (35%); 6. about 1/2 full (50%); 7. about 3/4 full (75%); 8. almost full (90%); and 9. fully packed (100%). After washing loose material off the outside of the stomach, it was opened and the contents flushed into a small dish. A Wild dissection scope at 90X or 180X was used to examine the contents. A subsample was viewed at 100X with a compound microscope to identify small organisms and fragments. The fragmented condition of the material precluded the counting of most items; the presence or absence of each type of material or item was recorded. Frequency of occurrence of a food item was calculated for the number of stomachs containing that item relative to the total number examined for the sampling period.

Two measures of feeding activity were considered: 1. the percentage of stomachs which were more than 5% full and contained organic matter (defined as feeding shrimp), and 2. the median percent fullness. Median percent fullness was used as the best measure of central tendency due to the highly skewed distribution of percent fullness values. A feeding index was calculated (% feeding shrimp x median % fullness) to obtain a measure of feeding activity for each depth and time period.

Sediment in stomach contents of shrimps

A sample of stomach contents was dried for 24 hours at 60°C in a tared crucible and weighed. Organic material was removed by heating at 500°C for 8 hours. The sample was cooled in a desiccator and weighed. The crucible and contents were dried at 60°C for 2-4 hours, cooled again in a desiccator, and re-weighed. A control with known amounts of sand and tissue was treated in the same manner.

The total mean percent dry weight sediment was calculated for each depth and time interval. A non-statistical method of data analysis, a two-way median polish (Velleman and Hoaglin 1981), was performed for mean percent dry weight sediment values from stomach contents of *P. borealis* captured at each depth and time interval to detect patterns in the data which do not show up in the combined means.[2] The median polish procedure smooths data in a two-way table (row = time interval, column = depth) by fitting an additive model consisting of a common effect, row effects, column effects and residual values. The model is,

original data value = common effect + row effect + column effect + residual value.

First, the median of the mean percent dry weight values in each row of the table is determined and subtracted from the values in its row, leaving a table with an additional column of row medians (partial row descriptors). A second sweep down columns acts on the residuals left by the first sweep. The median of each column is determined and subtracted, resulting in a new table of residuals and a new row of column medians (partial column descriptors). In addition, the median of the partial row descriptors is the first estimate of the common effect in the model. This two-step procedure is repeated and the results added together. The end products are row effects, column effects, a common effect, and residual values. Residual values within the table indicate whether the amount of sediment was greater than (positive value) or less than (negative value) that accounted for by the three types of effects.

[2] Computer programs MEDPOL and SED written by B. Sutherland are on file at the Institute of Marine Science, Fairbanks, AK 99701.

RESULTS

Hydrographic measurements

Density profiles of the water column at station AB 9, outside the sill, and station AB 4 in the inner bay show warm, freshwater surface layers (low density) of 10 m (sill depth) in summer (Figure 3). Water densities outside the sill (AB 9) often exceeded densities inside the sill (AB 4) down to sill depth in summer and winter. Oxygen profiles at station AB 4 (inside sill) show a decrease in oxygen content from June to December (Figure 3). Oxygen values measured over several years during summer and winter in the bottom water of the inner basin ranged from 4.51-6.45 ml/liter.

Suspended sediment load

The mean and range of depth of the euphotic zone (depth at which light intensity is 1% of solar radiation reaching the water surface) during the summer, as measured by the Secchi disc depth, are shown in Figure 4. In the sediment-laden plume adjacent to the glacier, Secchi depths were generally less than 1.0 m, which corresponds to a euphotic zone of less than 2.7 m. Turbidity decreased with distance from the glacier, but the maximum Secchi depth measured in the upper bay was only 5.0 m.

The depth of the euphotic zone in December, as measured by light meter, was much deeper than during the summer. The 1% light depths were 20 m and 18 m at stations AB 1 and AB 2, respectively.

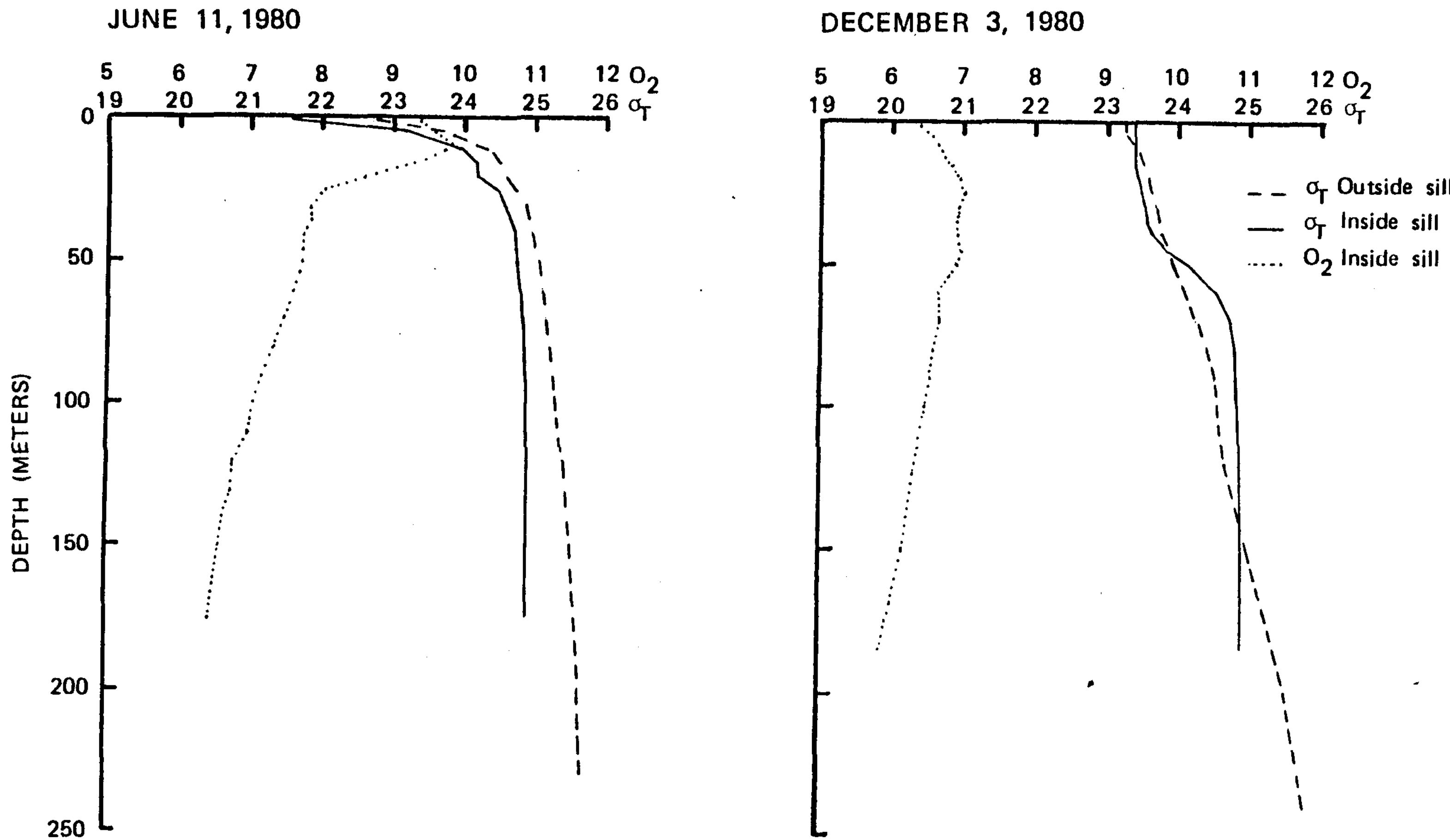

Figure 3. Water density outside (station AB 9) and inside (station AB 4) the sill during summer and winter, and seasonal change in oxygen content inside (station AB 4) the sill.

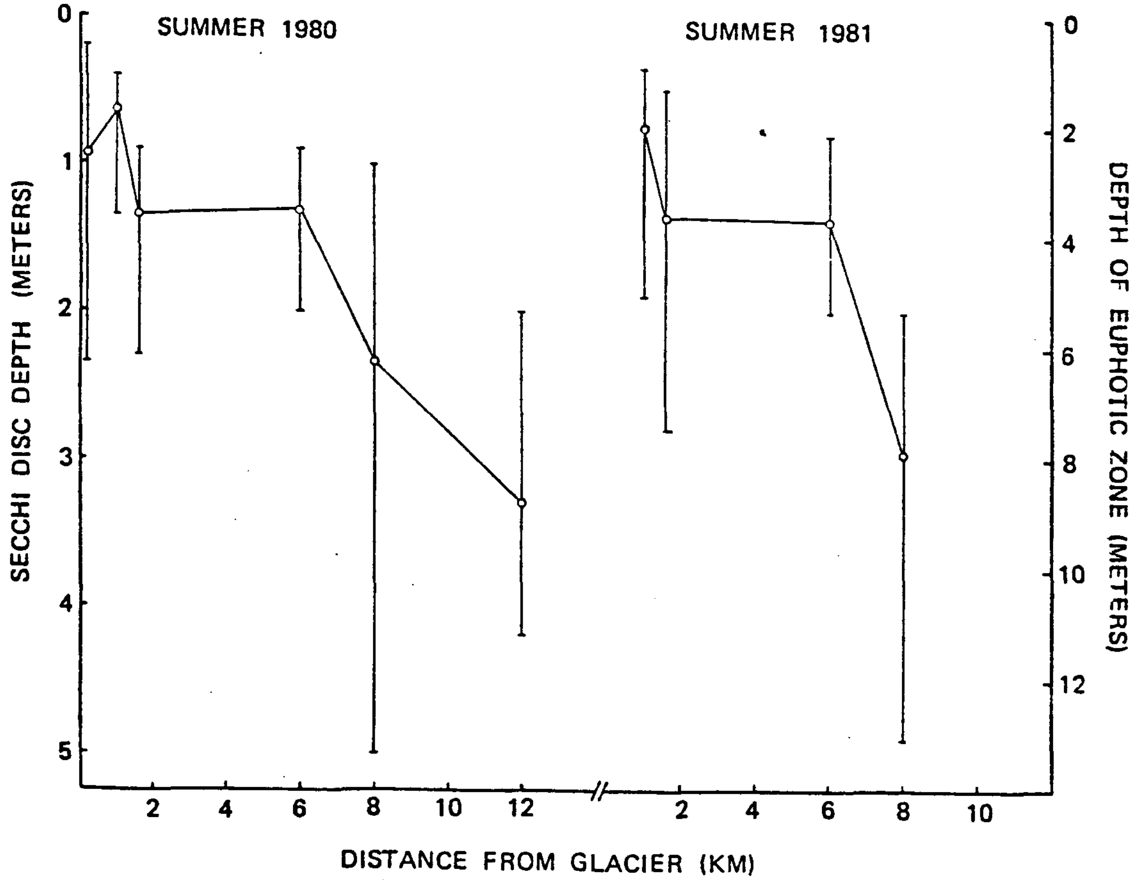

Figure 4. Mean (o) and range (I) of Secchi disc depths and depth of euphotic zone (1% of surface solar radiation) during the summers of 1980 and 1981.

The variation in Secchi depth during the tidal cycle at station AB 4 (2 km inside the sill) indicates that minimum Secchi depths (maximum turbidity) coincided with high water of the tidal cycle (Figure 5). Increased Secchi depths occurred with falling and low tides.

Suspended sediment load distribution by depth was characterized by fluctuations in the upper 25 m and decreases in value with depth, except for an increase in suspended sediment near the bottom (Figure 6). The relative amount of suspended sediment tended to decrease at all depths with increasing distance from the glacier. Variation from day to day at a single station was as large as the difference between stations.

Organic content of the sediment

A linear increase in nitrogen and organic carbon within the sediment (Figure 7) occurred with distance from the glacier to maximum values (0.104%, 0.91%) outside the sill (12 km, AB 9). The organic nitrogen content of a core taken 8 km (AB 4, inside sill) from the glacier decreased from the sediment surface (0.077%) to a minimum value at 3 m (0.058%), then increased slightly at 4 and 5 cm (0.065%) in the sediment (Figure 7). Organic carbon decreased linearly from 0.77% at the sediment surface to 0.54% at a depth of 3 cm, then remained constant down to 5 cm.

Density, diversity, and biomass of zooplankton

Approximately 30 zooplankton taxa, half of which were copepods, were identified from the vertical net tows (Table 3). The numerically dominant taxon was *Pseudocalanus* spp. for all samples (Appendix Table

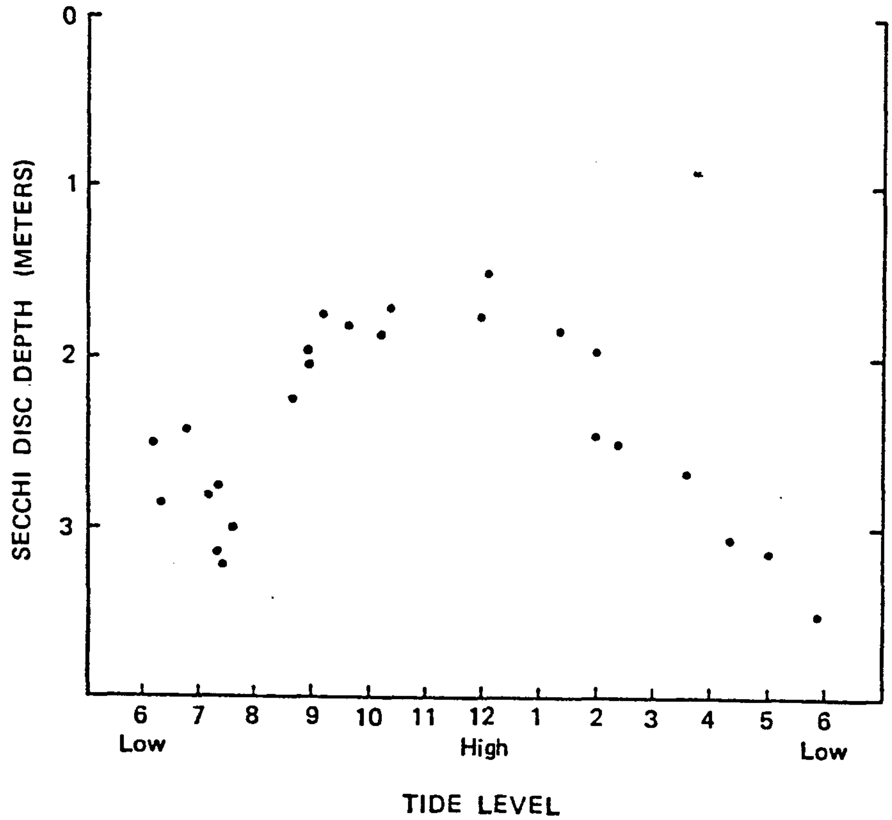

Figure 5. Variation in Secchi disc depth at station AB 4 (2 km inside the sill) during several stages of the tidal cycle, compiled from measurements taken during the summer of 1980. Data are smoothed by a running mean of five. Tide level is based on a twelve hour clock with 1200=high tide and 0600=low tide.

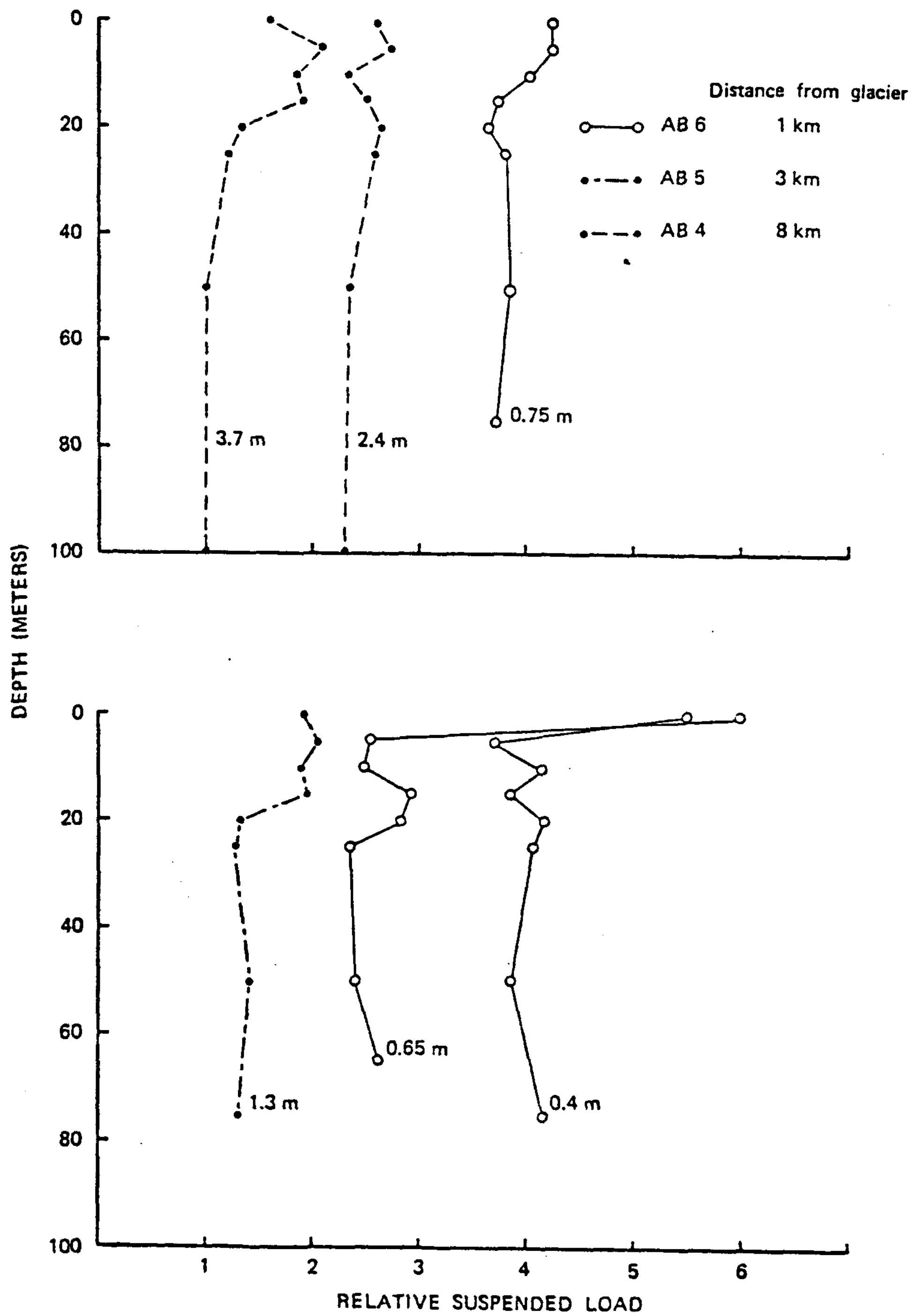

Figure 6. Distribution of suspended sediments (dry weight) in the water column. All stations are within the sill. Secchi disc depth at the time of sample collection is indicated next to each profile.

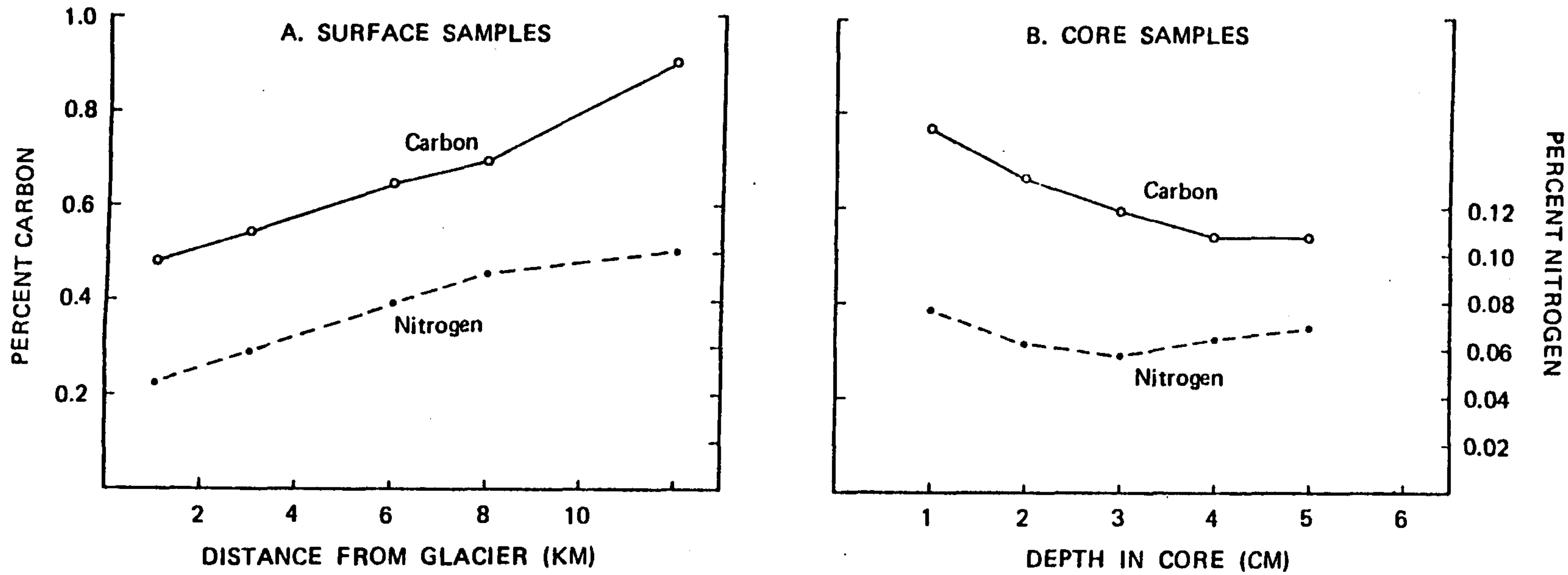

Figure 7. Organic carbon and nitrogen content of sediment. A. Surface sediment samples from five stations, November 11, 1981. B. Core sample taken at station AB 4, December 3, 1980.

Table 3. Zooplankton taxa collected by vertical net tows.

Cnidaria
- Hydrozoa
  - *Coryne tubulosa*
  - *Aglantha digitale*

Annelida
- Polychaeta
  - unidentified larvae

Mollusca
- Gastropoda
  - unidentified snail
  - *Limacina* sp.

Bryozoa
- cyphonautes larvae

Arthropoda
- Crustacea
  - Ostracoda
    - *Conchoecia* sp.
  - Copepoda
    - *Pseudocalanus* sp.
    - *Oithona similis*
    - *Oithona spinirostris*
    - *Acartia longiremis*
    - *Acartia tumida*
    - *Calanus plumchrus*
    - *Calanus marshallae*
    - *Calanus glacialis*
    - *Calanus cristatus*
    - *Metridia lucens*
    - *Metridia okhotensis*
    - *Oncaea* sp.
    - *Centropages abdominalis*
    - *Microcalanus* sp.
    - *Euchaeta elongata*
    - *Scolecithricella* sp.
  - Mysidacea
    - *Meterythrops robusta*
    - *Neomysis rayii*
  - Amphipoda
    - *Cyphocaris challengeri*
    - *Primno macropa*
    - *Parathemisto libelula*

Crustacea (continued)
- Euphausiacea
  - *Euphausia pacifica*
  - *Thysanoessa inermis*
  - *Thysanoessa longipes*
  - *Thysanoessa raschii*
- Decapoda
  - crab, euphausiid, crangonid and hippolytid shrimp larvae

Chaetognatha
- *Sagitta elegans*

Chordata
- Larvacea
  - *Oikopleura* sp.
- Teleosteii
  - unidentified larvae

A-1); *Oithona similis*, *Oncaea* sp., *Acartia longiremis* and *Metridia lucens* were also abundant. The ratio of small (smaller than *Metridia lucens*) to large (*Calanus* spp., *Metridia* spp. etc.) taxa is summarized in Table 4. Small species of copepods were always more abundant than the larger *Calanus* and *Metridia*. There was a tendency for a greater abundance of the large copepods outside the sill (AB 9) or just inside the sill (AB 4), with an increase in dominance of small copepods near the glacier (AB 1). Copepods and the chaetognaths *Sagitta elegans* were present in all samples.

The species richness, Simpson and Shannon indices calculated for the zooplankton densities (Appendix Table A-1) are shown in Table 5. The greatest number of taxa (25) occurred at station AB 4 (2 km inside the sill) during the summer and was reflected by the highest species richness of all sampling periods. Species richness was lower at other stations and decreased during the winter. The number of taxa was lowest (9) at station AB 1 in the winter. Low Simpson index values occurred in the samples with high Shannon index values indicating that where dominance was low, species diversity was high. The highest diversities occurred in the winter, although species richness was low during this period. During the summer more taxa were captured, but high numbers of a few copepods (*Pseudocalanus* spp., *Oithona* sp., and *Metridia* spp.) dominated the population.

The highest biomass values for transects sampled in summer and winter occurred inside the sill, 6-8 km from the glacier (Figure 8). There was a significant difference in the biomass between all stations in summer (Kruskal-Wallis test, H=11.4, d.f.=4, P=0.022) and winter

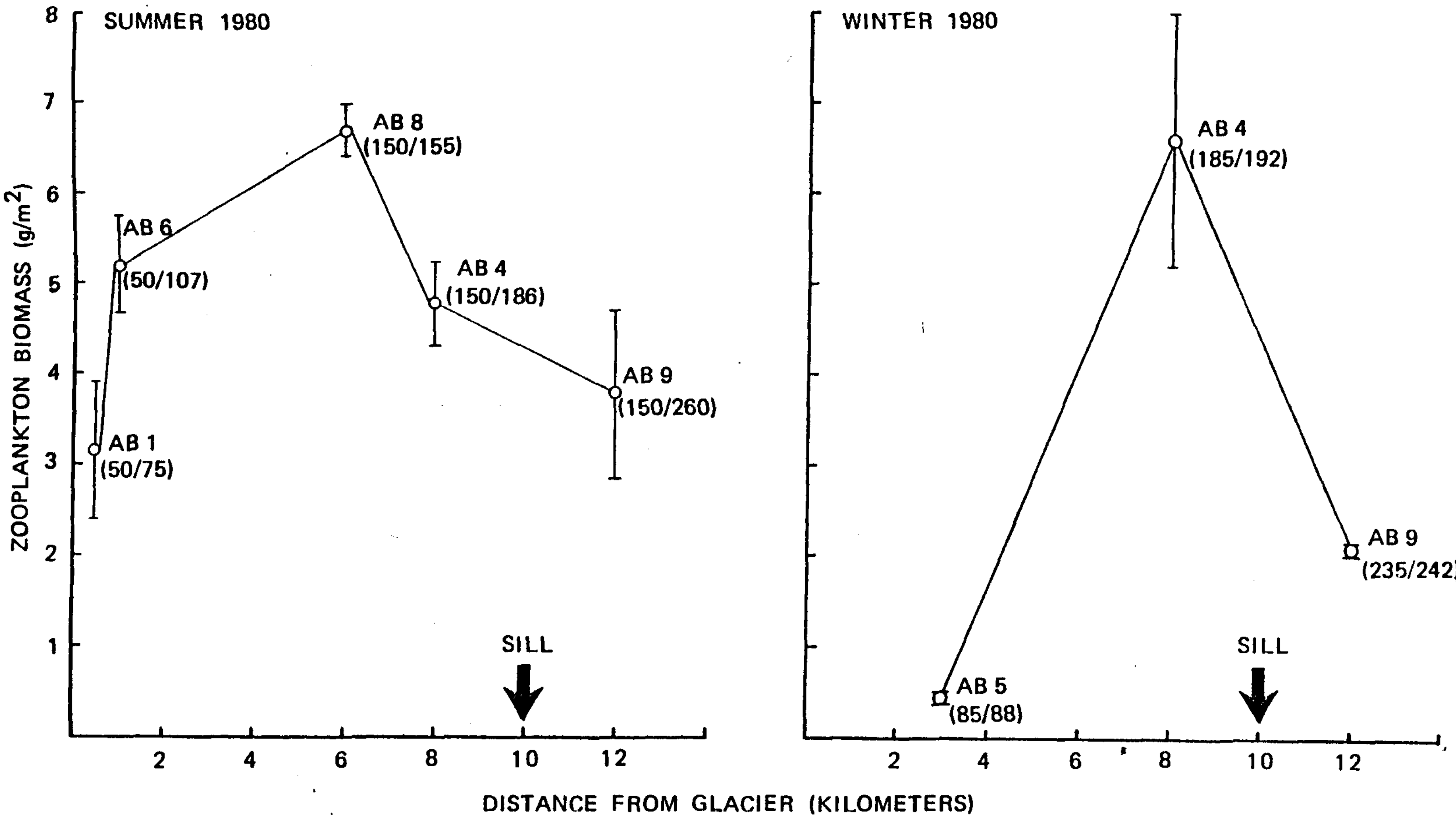

Figure 8. Mean (o) and standard error (I) of dryweight biomass (in g/m²) of zooplankton collected by vertical net tows (depth of tow/bottom depth) (mesh size = 202μ or 216μ). Difference in biomass was significant between stations during the summer (Kruskal-Wallis test, H=11.4, d.f.=4, P=0.022) and winter (Kruskal-Wallis test, H=4.57, d.f.=2, P=0.067).

Table 4. Comparison of numbers of small and large copepods collected by vertical net tows. Net mesh = 202μ or 216μ.

Station	AB 1	AB 1	AB 1	AB 4	AB 4	AB 9
Date of collection	6-16-80	7-22-80	12-4-79	6-18-80	12-4-79	6-15-80
Total number of copepods (no./m^2)	456,200	267,000	36,200	775,000	87,170	652,000
Number of small copepods (no./m^2)	454,570	265,400	35,900	756,090	73,400	605,200
Number of large copepods (no./m^2)	1,643	1,530	255	18,887	13,770	46,800
Small/large	277/1	173/1	141/1	40/1	5.3/1	13/1

Table 5. Species richness, dominance, and diversity indices for zooplankton collected by vertical net tows. Calculations are based on density values included in Appendix Table A-1.

Station	AB 1	AB 1	AB 1	AB 4	AB 4	AB 9
Date of collection	6-16-80	7-22-80	12-4-79	6-18-80	12-4-79	6-15-80
Number of taxa	17	17	9	25	14	13
Species richness	1.225	1.279	0.750	1.768	1.120	0.896
Simpson dominance index	0.517	0.683	0.378	0.485	0.213	0.547
Shannon diversity index	0.414	0.311	0.569	0.466	0.761	0.396

(Kruskal-Wallis test, H=4.57, d.f.=2, P=0.067). The maximum biomass (at station AB 4) in December (6.6g/m^2) was about the same as the maximum biomass measured (at station AB 8) during the summer (6.86g/m^2).

A relatively uniform vertical distribution of zooplankton biomass was observed near the glacier (AB 6) on a single sampling date during daylight in the summer (Figure 9, Appendix Table A-2). Biomass data from near the sill (AB 4) on the same morning showed the major portion of the biomass below 100 m.

Invertebrates collected with the Isaac-Kidd midwater trawl included the same species as those collected by vertical zooplankton tows with the addition of the shrimp *Pasiphaea pacifica* and the euphausiid *Thysanoessa spinifera* (Appendix Table A-3). Euphausiids (*Thysanoessa* spp.) collected were the same ones fed upon by shrimps captured with the Isaac-Kidd trawl or in vertical tows (see food habits section). Twenty-five (93%) of the *Pandalus borealis* captured in the midwater trawl were males; the others were adult females. The mean carapace length of the *P. borealis* taken by midwater trawl was 17.4 mm (Appendix Table A-3) as compared to 18.7 mm for those taken by otter trawl in the same area (Appendix Table A-6, trawl 3).

Abundance dominance, and diversity of benthos:

van Veen grab collections

Approximately seventy taxa, composed primarily of polychaetes, mollusks, and crustaceans were identified from grab samples from stations AB 4, AB 5, AB 8, and AB 9 (Table 6, Appendix Table A-4). The number of benthic taxa, density, biomass, species richness, and indices

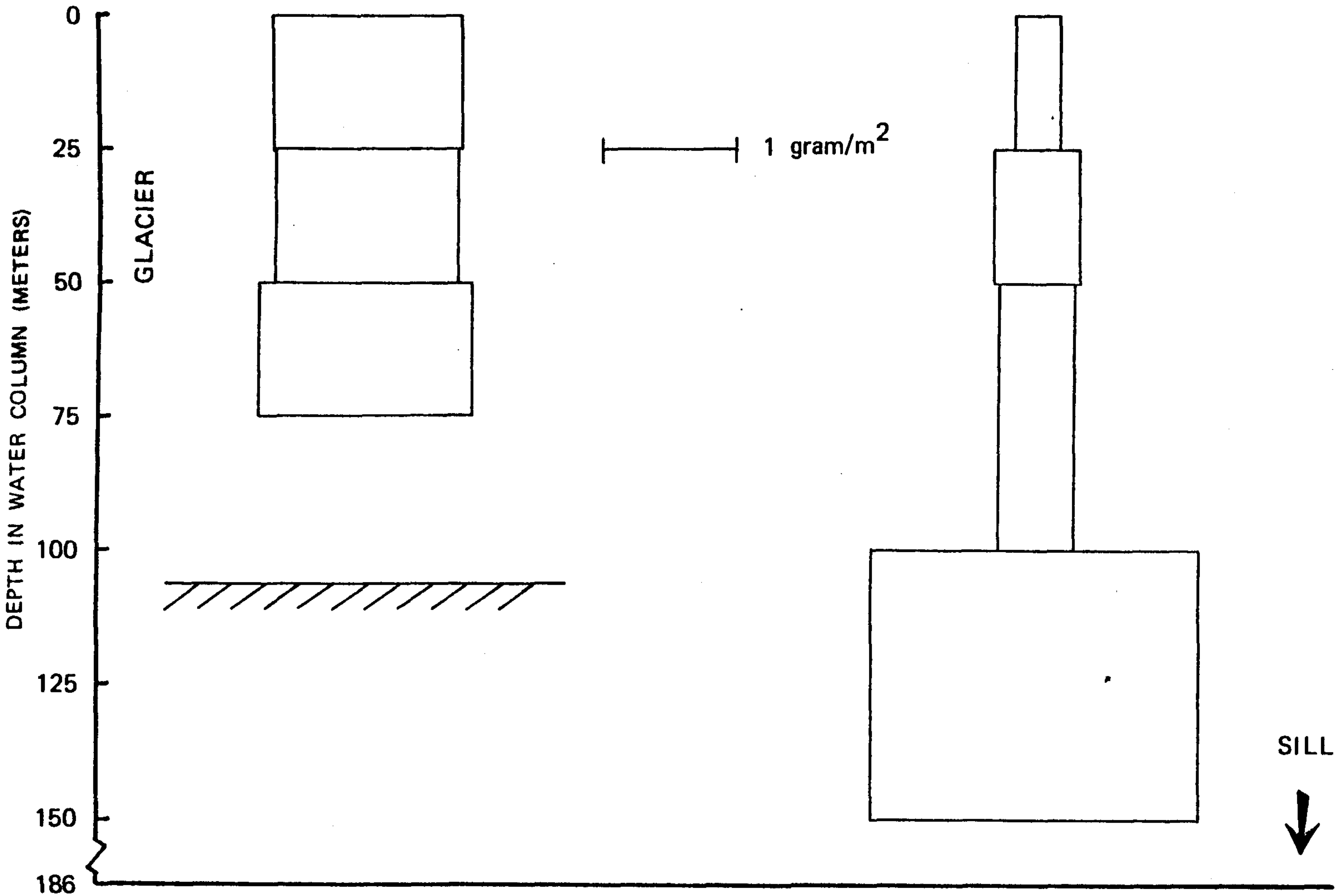

Figure 9. Distribution of zooplankton biomass (dry weight) collected by vertical net tows (mesh=216µ) at stations AB 6 and AB 4 during daylight on July 22, 1980.

Table 6. Taxa identified from van Veen grab collections in Aialik Bay, December 3, 1980 and November 11, 1981. Non-benthic taxa excluded for biomass and indices are indicated by *.

Protozoa
- Foraminifera

Cnidaria
- Anthozoa
  - *Stylatula gracile*

Rhynchocoela
- unknown Rhynchocoela
- *Cerebratulus* sp.

Annelida
- Polychaeta
  - Polynoidae
  - *Anaitides* sp.
  - *Nephtys* sp.
  - *Nephtys cornuta*
  - *Nephtys punctata*
  - *Glycera capitata*
  - *Goniada annulata*
  - *Onuphis iridescens*
  - *Lumbrineris* sp.
  - *Ninoe* sp.
  - Paraonidae
  - *Tauberia gracilis*
  - *Polydora* sp.
  - *Prionospio* sp.
  - *Spio* sp.
  - *Pygiospio* sp.
  - *Spiochaetopterus* sp.
  - Cirratulidae
  - *Tharyx* sp.
  - *Scalibregma inflatum*
  - *Ophelina acuminata*
  - *Sternaspis scutata*
  - Capitellidae
  - *Heteromastus filiformis*
  - Maldanidae
  - *Maldane* sp.
  - *Maldane glebifex*
  - *Praxillella* sp.
  - *Praxillella gracilis*
  - *Rhodine* sp. fragments
  - *Myriochele heeri*
  - *Myriochele occulata*
  - *Pectinaria* sp.
  - Ampharetidae
  - *Ampharete* sp.
  - *Ampharete finmarchica*

- Polychaeta (cont.)
  - *Lysippe labiata*
  - *Melinna cristata*
  - *Artacama conifera*
  - *Terebellides stroemii*
  - *Trochochaeta multisetosa*
- Hirudinea

Mollusca
- *Chaetoderma robusta*
- Pelecypoda
- *Nucula tenuis*
- *Nuculana* sp.
- *Yoldia* sp.
- *Yoldia thraciaeformis*
- *Axinopsida* sp.
- *Axinopsida serricata*
- *Axinopsida viridis*
- *Odontogena borealis*
- *Clinocardium* sp.
- *Macoma* sp.
- *Pandora grandis*
- *Cardiomya* sp.
- *Cardiomya planetica*
- *Solariella* sp.
- Turridae
- *Cylichna* sp.
- *Dentalium* sp.

Arthropoda
- Ostracoda
- **Euchaeta elongata*
- **Meterythrops robusta*
- *Eudorella emarginata*
- *Lysianassidae
- **Parathemisto pacifica*
- *Euphausiacea
- **Thysanoessa inermis*
- **Thysanoessa longipes*
- **Pandalus borealis*
- **Insecta*

Brachiopoda
- *Terebratulina unguicula*

Echinodermata
- *Brisaster townsendi*
- Ophiuridae

of dominance and diversity are summarized by station in Table 7. Data from single grabs collected at three stations (AB 1, AB 2, AB 4) in December 1979 and one station (AB 6) in November 1981 are summarized in Table 8 (Appendix Table A-5). Twenty-three taxa occurred at the stations closest to the glacier (AB 5, AB 8) (Table 7). The number of taxa increased to 28 at station AB 4, inside the sill, and to 38 at station AB 9, outside the sill. The abundance of individuals increased along the transect from near the glacier (AB 5) to a maximum just inside the sill (AB 4). The lowest abundance occurred outside the sill (AB 9). Biomass values at each station varied widely and showed no pattern. Dominance, as shown by the Simpson index, was highest near the glacier and decreased with distance away from the glacier. Diversity, as measured by the Shannon index, increased away from the glacier, as did species richness.

Nine taxa occurred at all stations: *Tharyx* sp., *Nephtys punctata*, *Heteromastus filiformis*, *Melinna cristata*, *Nuculana* sp., *Lumbrineris* sp., *Myriochele occulata*, *Terebellides stroemii*, and *Chaetoderma robusta*. The first five occurred in high densities (>32/m²) at one or more stations; the remaining four taxa were always present in low numbers.

Benthic organisms are listed by geometric classes of abundance in Table 9. The differences in distribution of taxa between stations inside and outside the sill are illustrated by the change in the shape of the geometric class abundance curves (Figure 10). The inside stations had fewer taxa in the lower geometric classes (II-V) and abundance ranged from class II to class VIII (2-255/m²). The outside

Table 7. Density, biomass, species richness, dominance and diversity indices of benthos collected by van Veen grab on December 3, 1980 and November 11, 1981.

Station	Year	Distance from glacier	No. taxa	No. individuals per meter²	Biomass (g/m²)	Species richness	Simpson index	Shannon index
AB 5	1980	3 km	12	282	13.6	1.95	0.329	0.64
AB 5	1981	3 km	23	499	47.7	3.54	0.185	0.92
AB 8	1981	6 km	23	534	18.8	3.50	0.137	1.00
AB 4	1980	8 km	22	542	36.0	3.35	0.133	1.03
AB 4	1981	8 km	28	796	14.1	4.04	0.128	1.06
AB 9	1980	12 km	38	294	32.4	6.51	0.042	1.44
AB 9	1981	12 km	32	186	133.0	5.93	0.044	1.40

Table 8. Non-quantitative benthic grab data;

Station	Distance from glacier	Depth
van Veen grabs (0.1 m^2), December 4, 1979:		
AB 1	0.5 km	38 m
AB 2	4.5 km	40 m
AB 4	8 km	186 m
Ekman grab (0.055m^2), November 11, 1981:		
AB 6	1 km	107 m

one sample per station.

No. individuals/m^2	Number of taxa	Biomass (g/m^2)
50	4	
560	11	
150	6	
655	13	61.6

Table 9. Distribution of all benthic organisms collected by van Veen grab into geometric classes.

Geometric class	II 2-3 individuals/m²	III 4-7/m²	IV 8-15/m²	V 16-31/m²	VI 32-63/m²	VII 64-127/m²	VIII 128-255/m²
AB 9 1980	*Anaitides* sp. *Nephtys cornuta* *Glycera capitata* *Heteromastus filiformis* *Praxillella gracilis* *Praxillella* sp. *Rhodine* sp. fragments *Pectinaria* sp. *Melinna cristata* Turridae *Brisaster townsendi* Ophiuridae	*Stylatula gracile* *Tauberia gracilis* *Myriochele heeri* *Ampharete* sp. *Yoldia* sp. *Cardiomya planetica* *Solariella* sp. *Dentalium* sp. *Terebratulina unguicula*	Rhynchocoela *Goniada annulata* *Onuphis iridescens* *Ninoe* sp. *Spio* sp. *Spiochaetopterus* sp. *Myriochele occulata* *Terebellides stroemii* *Nucula tenuis* *Nuculana* sp. *Odontogena borealis* Ostracoda *Eudorella emarginata*	*Nephtys punctata* *Lumbrineris* sp. *Sternaspis scutata* *Chaetoderma robusta*			
AB 4 1980	Rhyncocoela *Ophelina acuminata* *Artacama conifera* *Clinocardium* sp.	*Lysippe labiata* *Trochochaeta multisetosa* *Nucula tenuis* *Axinopsida serricata* *Macoma* sp. Turridae	*Nephtys cornuta* *Maldane glebifex* *Chaetoderma robusta* *Eudorella emarginata*	*Lumbrineris* sp. *Heteromastus filiformis*	*Tharyx* sp. *Melinna cristata*	*Nephtys punctata* *Nuculana* sp. *Axinopsida viridis*	*Polydora* sp.
AB 5 1980	*Myriochele heeri* *Lysippe labiata* *Terebellides stroemii* *Chaetoderma robusta*	*Heteromastus filiformis* *Trochochaeta multisetosa* *Axinopsida serricata*	Foraminifera *Axinopsida viridis*	*Nuculana* sp.		*Nephtys punctata*	*Melinna cristata*

Table 9 (continued).

Geometric class	II 2-3 individuals/m²	III 4-7/m²	IV 8-15/m²
AB 9 1981	*Stylatula gracile* *Nephtys cornuta* *Heteromastus filiformis* *Maldane* sp. *Rhodine* sp. fragments *Ampharete* sp. *Axinopsida serricata* *Odontogena borealis* *Pandora grandis* Ostracoda	Rhyncocoela *Goniada annulata* *Onuphis iridescens* *Ninoe* sp. *Spiochaetopterus* sp. *Tharyx* sp. *Praxillella gracilis* *Terebellides stroemii* *Nuculana* sp. *Yoldia thraciaeformis* *Cardiomya* sp. *Solariella* sp. *Dentalium* sp.	*Lumbrineris* sp. *Tauberia gracile* *Sternaspis scutata* *Myriochele occulata* *Chaetoderma robusta* *Nucula tenius* *Brisaster townsendi*
AB 4 1981	*Anaitides* sp. *Glycera capitata* *Nephtys cornuta* Paroanidae *Pygiospio* sp. *Scalibregma inflatum* Pelecypoda *Dentalium* sp.	*Myriochele occulata* Ampharetidae *Chaetoderma robusta* *Axinopsida serricata* Turridae	*Nephtys* sp. *Prionospio* sp. *Maldane glebifex* *Nucula tenuis* *Cylichna* sp. *Eudorella emarginata*
AB 8 1981	*Nephtys* sp. *Nephtys cornuta* *Myriochele heeri* *Trochochaeta multisetosa* *Cylichna* sp.	*Lumbrineris* sp. *Prionospio* sp. Maldanidae *Ampharete finmarchica* *Lysippe labiata* *Terebellides stroemii* *Chaetoderma robusta* *Nucula tenuis* *Macoma* sp.	*Heteromastus filiformis* *Myriochele occulata*
AB 5 1981	*Cerebratulus* sp. Polynoidae *Nephtys* sp. *Lumbrineris* sp. *Polydora* sp. *Prionospio* sp *Maldane glebifex* *Myriochele heeri* *Ampharete finmarchica* *Trochochaeta multisetosa* Hirudinea *Chaetoderma robusta* *Eudorella emarginata*	*Axinopsida serricata*	*Heteromastus filiformis* *Lysippe labiata*

V 16-31/m^2	VI 32-63/m^2	VII 64-127/m^2	VIII 128-255/m^2
Nephtys punctata *Eudorella emarginata*			
Lumbrineris sp. *Terebellides stroemii* *Nuculana* sp.	*Melinna cristata*	*Nephtys punctata* *Tharyx* sp. *Heteromastus filiformis*	*Polydora* sp. *Axinopsida viridis*
	Polydora sp. *Maldane glebifex* *Nuculana* sp.	*Tharyx* sp. *Melinna cristata* *Axinopsida viridis*	*Nephtys punctata*
Foraminifera *Tharyx* sp. *Myriochele occulata*	*Nuculana* sp.	*Nephtys punctata* *Axinopsida viridis*	*Melinna cristata*

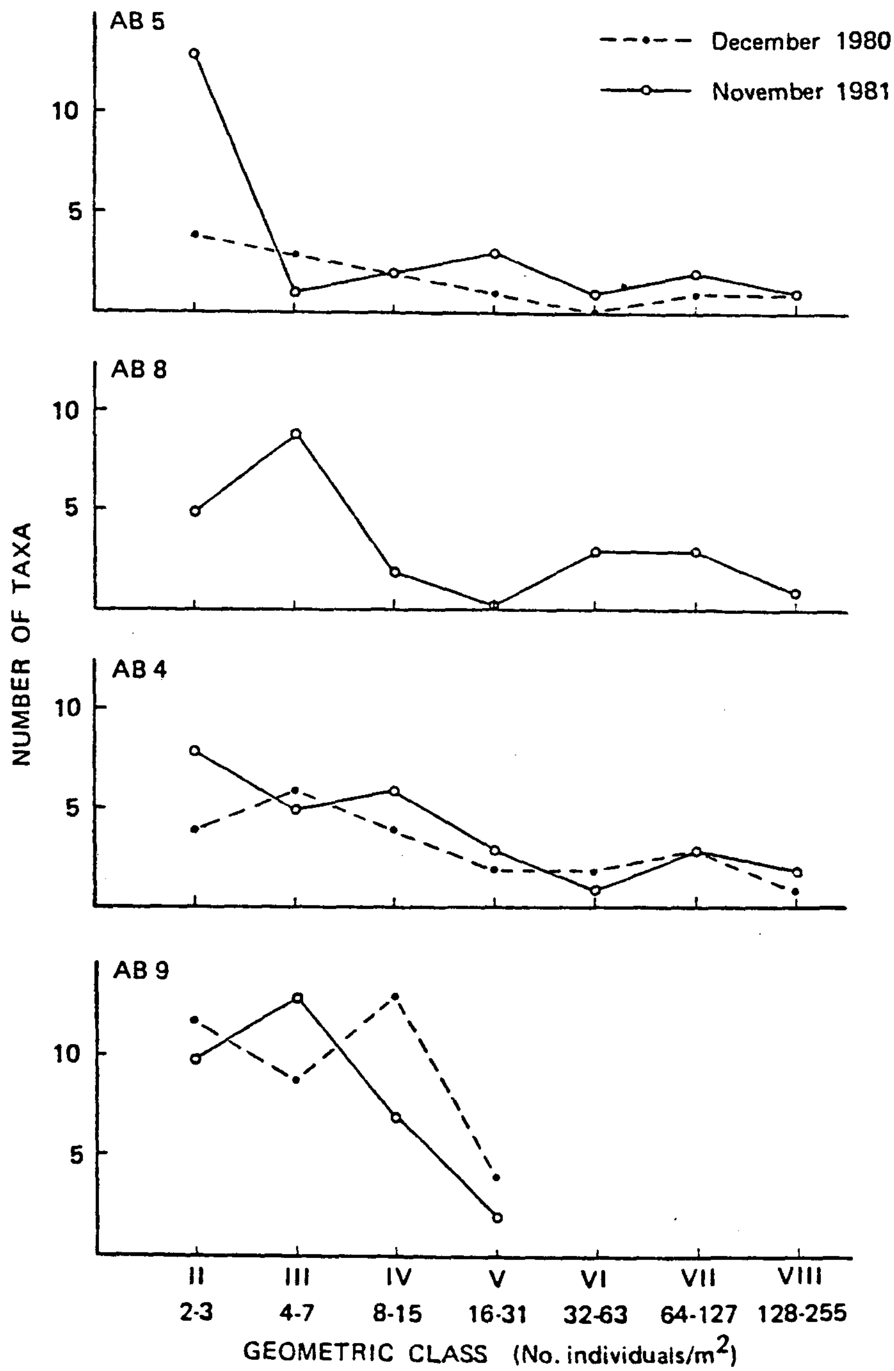

Figure 10. Distribution of benthic taxa by geometric class of abundance at each station. The sill is located between stations AB 4 and AB 9.

station (AB 9) had more taxa in classes II-IV (2-15/m^2) and no taxa in abundance classes greater than V (16-31/m^2).

Adjacent stations along the transect were similar as shown by Sørenson similarity coefficient values (Table 10). Stations AB 4, AB 5, and AB 8, inside the sill, shared many of the same taxa. Station AB 9 (outside the sill) shared few taxa with stations AB 5 and AB 8, but shared slightly less than half of the taxa with station AB 4 (inside the sill) in the 1981 samples (Sørenson = 0.4333). Fewer taxa were shared by stations AB 9 and AB 4 in 1980 (Sørenson = 0.3333). Samples collected in 1980 at stations AB 5 and AB 9 were similar to those collected in 1981 at the same stations (Sørenson = 0.6286, 0.7429). Less similarity was observed between 1980 and 1981 samples from station AB 4 (Sørenson = 0.6000).

Abundance and distribution of epibenthos:
otter trawl and pot collections

Pandalus borealis was the most abundant species captured by otter trawl (Figure 11) from December 1979 through December 1980 (Appendix Table A-6). The total number of *P. borealis* captured per trawl, and the number/km trawled varied by as much as two orders of magnitude. *Pandalus goniurus*, *Pandalopsis dispar*, and *Crangon communis* were common, and occasionally occurred in high numbers.

Pandalid shrimps were distributed throughout the upper bay. *Pandalus borealis*, *P. goniurus*, and *P. hypsinotus* were collected by trawl or pots at all stations (Figure 11). *Pandalus platyceros* was captured only once in the region northwest of Squab Island, at station

Table 10. Sørenson similarity indices between pairs of stations along a transect in Aialik Bay. This index compares presence/absence of infaunal species.

$$\text{Sørenson similarity index} = \frac{2(\text{total taxa shared by stations A and B})}{(\text{total taxa A}) + (\text{total taxa B})}$$

Between station comparisons:		Sørenson Index	
AB 8 vs. AB 5			
1981	1981	0.7391	more similar
AB 4 vs. AB 8			↑
1981	1981	0.6667	
AB 4 vs. AB 5			
1981	1981	0.5882	
AB 4 vs. AB 5			
1980	1980	0.5294	
AB 4 vs. AB 9			
1981	1981	0.4333	
AB 9 vs. AB 8			
1981	1981	0.4000	
AB 4 vs. AB 9			
1980	1980	0.3333	
AB 9 vs. AB 5			
1981	1981	0.3273	↓
AB 9 vs. AB 5			less
1980	1980	0.2800	similar
Within station comparisons:			
AB 9 vs. AB 9			
1980	1981	0.7429	
AB 5 vs. AB 5			
1980	1981	0.6286	
AB 4 vs. AB 4			
1980	1981	0.6000	

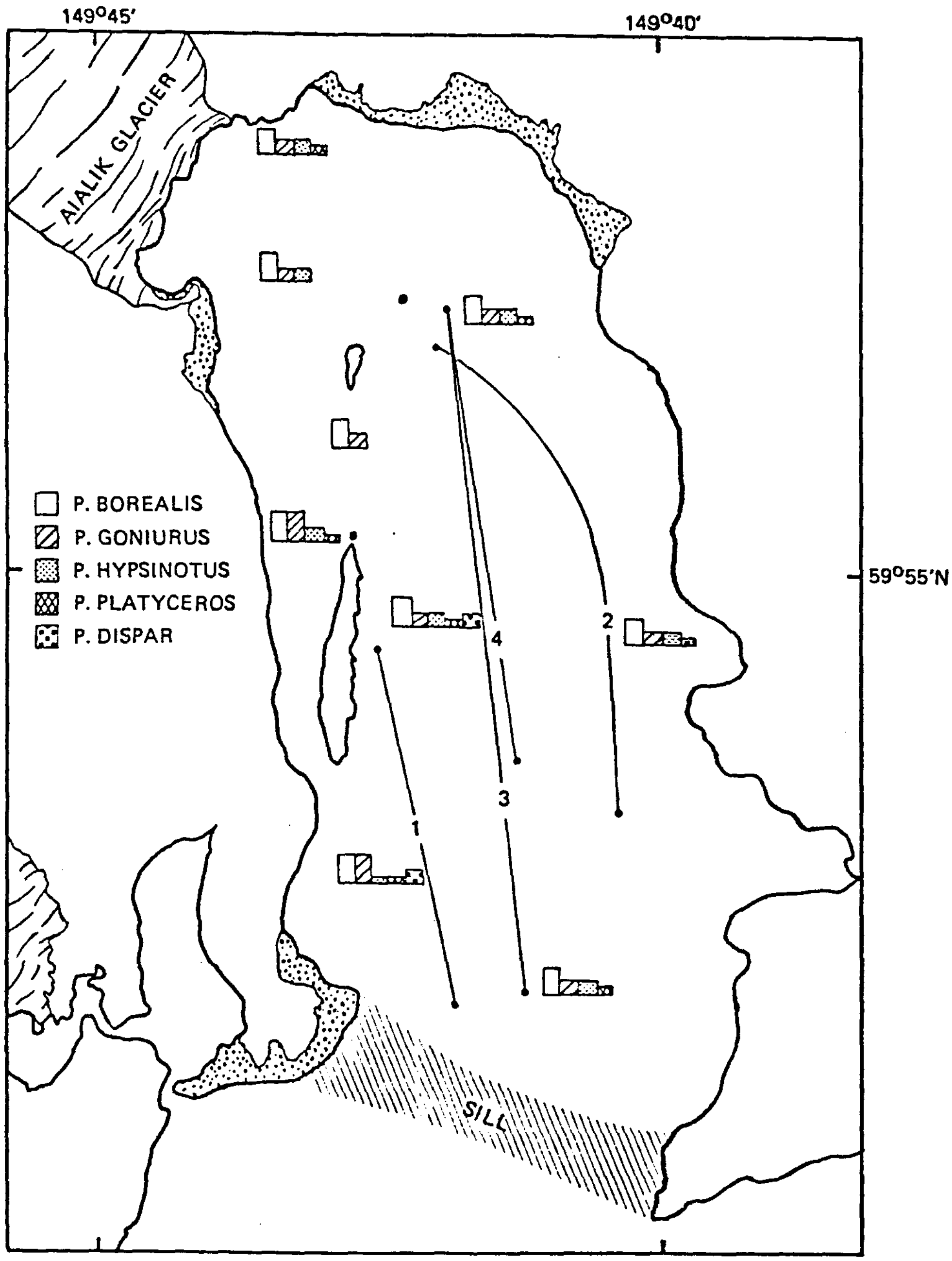

Figure 11. Location of benthic otter trawl (numbered lines) and shrimp pot (all other locations) collections, 1979-1981, and relative abundance of pandalid shrimps captured (☐ =abundant), ☐ =common, ▭ =rare).

AB 1, and occurred in low numbers at other locations in the bay. Collection of *Pandalopsis dispar*, which was never captured in a shrimp pot (see section on vertical and diel distribution of shrimps) was restricted to trawl sites south and east of Squab Island.

Twenty-four percent and 6.4% of the *P. borealis* captured by trawl and pots were ovigerous in December 1979 and December 1980, respectively (Appendix Table A-6). The population sampled in December 1980 was composed primarily of young *P. borealis*; the sample included 482 male, 6 transitional, and 122 female shrimp.

Vertical and diel distribution of pandalid shrimps

The number of pandalid shrimps captured in pots suspended at five levels in the water column for 24-hour periods at stations AB 6 and AB 4 is shown in Figure 12. Data were combined to make three 24-hour periods for station AB 6: July 14-15 and July 20-21, 1980, and May 26 and June 5, 9, and 10, 1981 (Appendix Table A-7). The catch from one 24-hour period at station AB 4 is shown. The catch patterns demonstrate several features: 1. the number of shrimps captured was greatest at mid-depths in the water column, between approximately 30-95 m; 2. *Pandalus borealis* and *P. goniurus* were captured at all depths, while *P. hypsinotus* and *P. platyceros* were captured only on the bottom; 3. *Pandalopsis dispar* was not captured in shrimp pots; 4. *Pandalus borealis* dominated captures at all depths except at the bottom.

Pandalus borealis were distributed throughout the water column at station AB 6, excluding the upper few meters, at all times, with relatively higher numbers in the upper half (Figure 13). Shrimp were

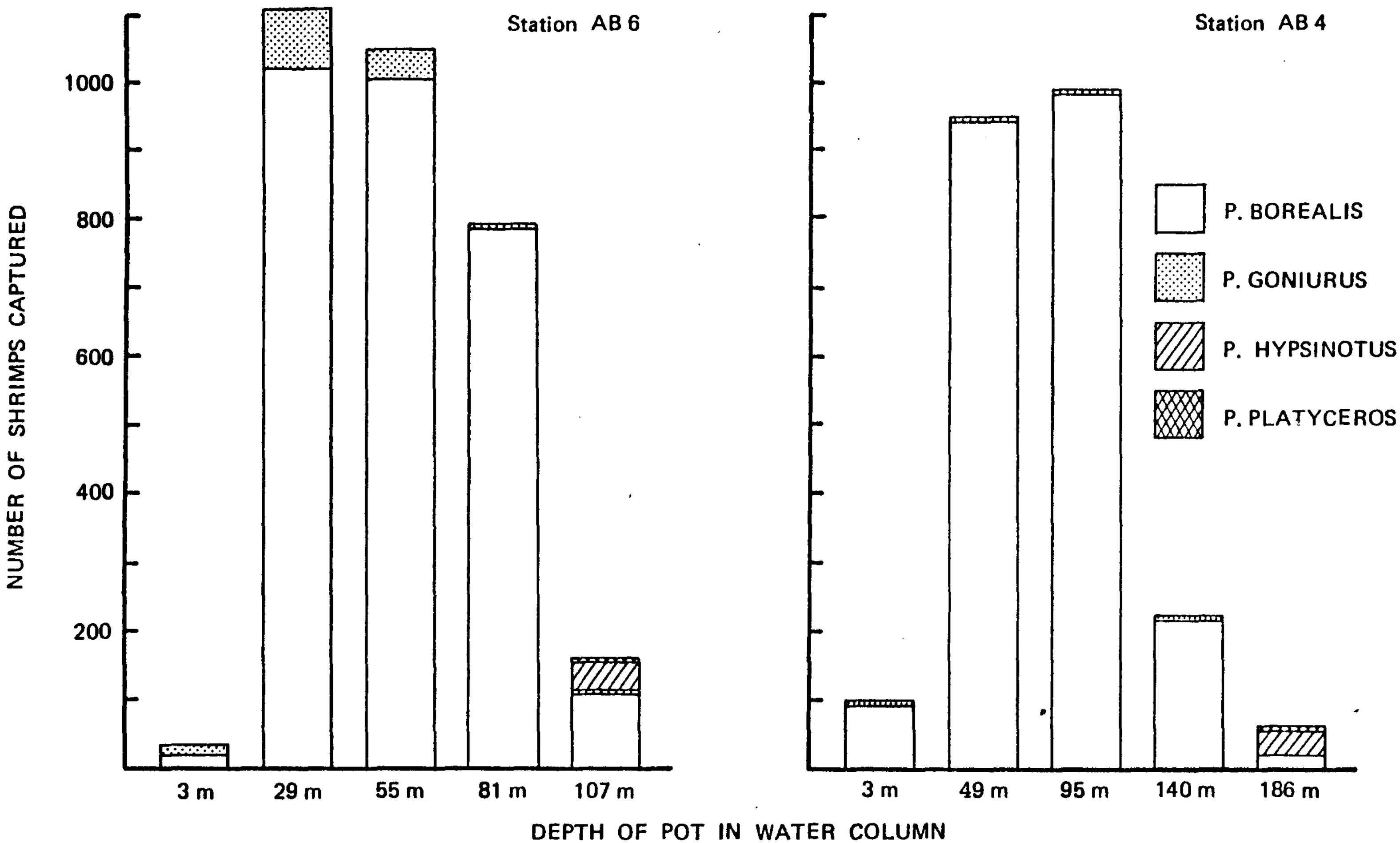

Figure 12. The number of pandalid shrimps captured in pots suspended at five depths in the water column. Bottom depth = 107 m at station AB 6 and 186 m at station AB 4. Three 24-hour periods were combined for station AB 6: July 14-15 and July 20-21, 1980, and May 26, and June 5, 9, 10, 1981. One 24-hour period is shown for station AB 4: July 4-5, 1980.

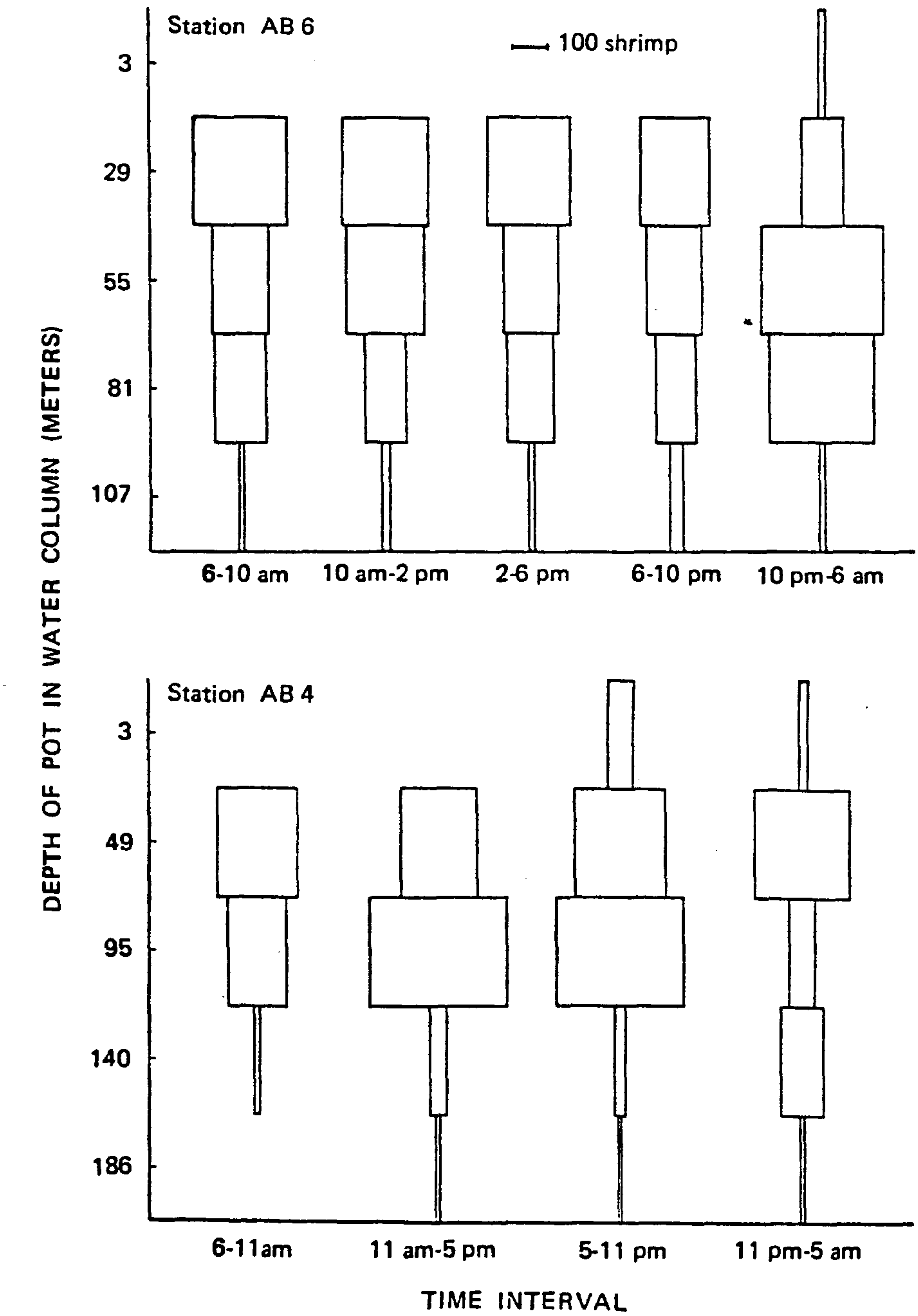

Figure 13. The number of *Pandalus borealis* captured during 24-hour periods in pots suspended at five depths in the water column. Three 24-hour periods were combined for station AB 6. The difference in number was significant between depths, but not between time intervals, and no depth x time interaction was found.

collected near the water surface (3 m) only during the dark period (10 pm-6 am). The number of shrimp captured was significantly different between depths (ANOVA, $F=10.6$, d.f.$=4,50$, $P<0.05$), but not between time intervals (ANOVA, $F=0.57$, d.f.$=4,50$, $P=0.68$). No depth-by-time interaction was found (ANOVA, $F=0.71$, d.f.$=16,50$, $P=0.77$).

Pandalus borealis at station AB 4 demonstrated a different pattern of distribution than that shown at station AB 6 (Figure 13). Capture of shrimp was more concentrated in the middle and upper layers at station AB 4 than at station AB 6, and the catch on the bottom was less. Shrimp were captured near the surface (3 m) during the evening (5-11 pm) and night-time (11 pm-6 am) periods. The number of shrimp captured at station AB 4 was significantly different between depths (ANOVA, $F=13.66$, d.f.$=4,12$, $P<0.05$), but not between times (ANOVA, $F=1.48$, d.f.$=3,12$, $P=0.27$).

Size and sex distribution of *Pandalus borealis* and *P. goniurus*

The catch of *Pandalus borealis* from pots suspended at five levels in the water column at station AB 6 (Figure 14) was dominated by male shrimp in the upper three pots (3, 29, 55 m). Between 55 m and 81 m a shift in the composition of the catch occurred with females dominating the catch at 81 m and 107 m. At station AB 4 (Figure 14) male and female *P. borealis* were captured in approximately equal numbers in the upper three pots (3, 49, 95 m). A change in the composition of the catch occurred between 95 m and 140 m with females outnumbering males in the lower two pots. The percentage of transitional shrimp captured at station AB 4 was highest at mid-depths (49-140 m). A trend of increasing

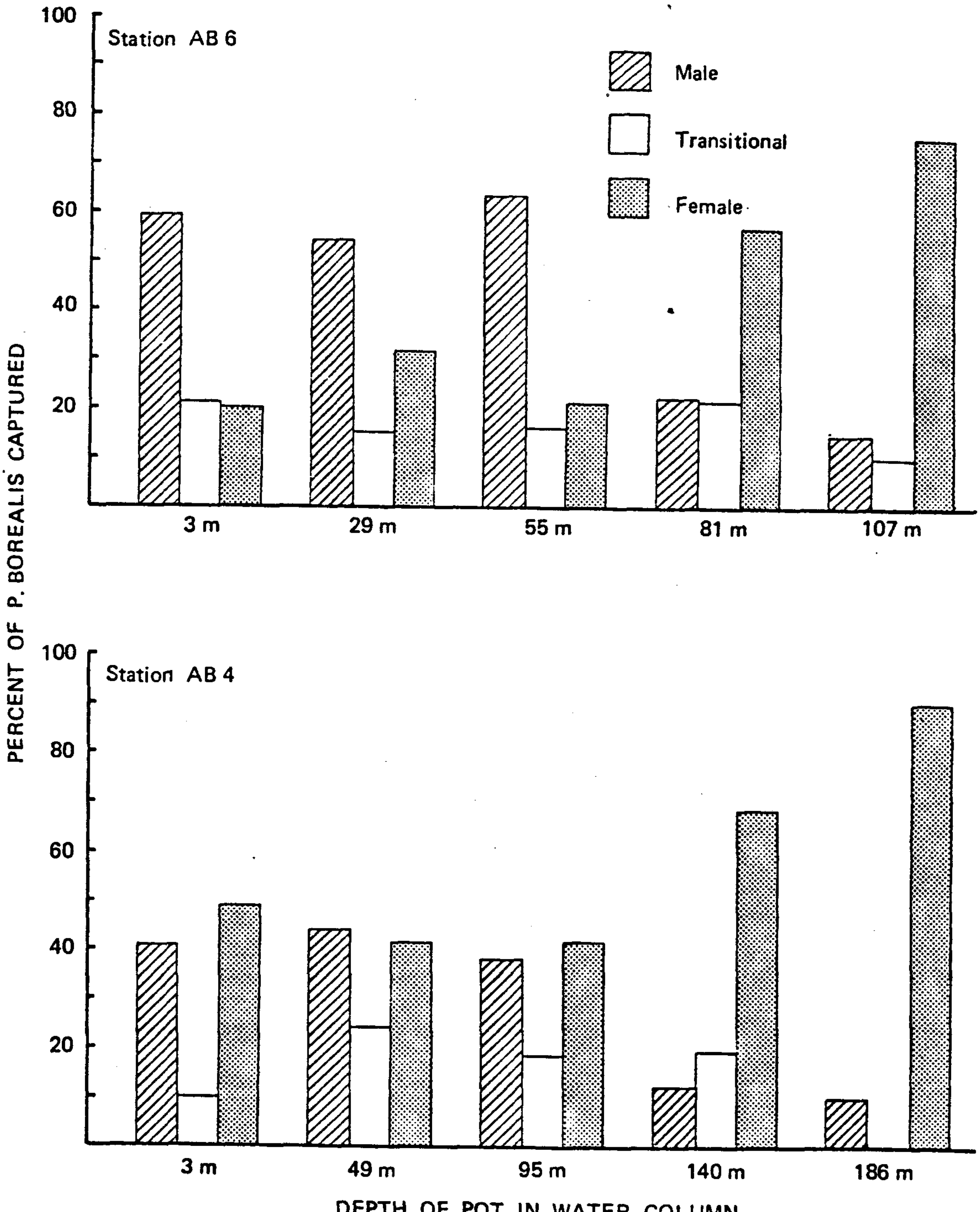

Figure 14. Distribution of *Pandalus borealis* by sex and depth of capture in vertically suspended shrimp pots at stations AB 6 and AB 4 during the summers of 1980 and 1981 (N=875 at AB 6, N=361 at AB 4).

size with depth at both stations is demonstrated by the carapace length data (Table 11).

Pandalus borealis were smaller at station AB 6 than at station AB 4. In the summer of 1980, at stations AB 6 and AB 4, respectively, the mean carapace length for males was 16.4 mm and 17.7 mm (t-test, t=6.60, d.f.=359, P=0.000), for transitionals it was 19.0 mm and 19.4 mm (t-test, t=2.85, d.f.=144, P=0.005), and for females it was 19.9 mm and 20.8 mm (t-test, t=7.57, d.f.=355, P=0.000). In December 1980 at these stations, the mean carapace length of males was 16.9 mm and 17.1 mm (t-test, t=1.84, d.f.=373, P=0.067), for females it was 19.7 mm and 20.2 mm (t-test, t=2.46, d.f.=96, P=0.016), and for females with eggs it was 19.2 mm and 19.5 mm (t-test, t=1.12, d.f.=22, P>0.05), respectively. The smaller size of shrimp at station AB 6 relative to station AB 4 during both these periods was significant at the 95% confidence level, except for males and for females with eggs in December.

The sex composition of *Pandalus goniurus* captured in pots suspended at five levels in the water column at station AB 6 during May and June 1981 showed a pattern similar to *P. borealis* (Figure 15). Juveniles and males dominated the catch in the upper two pots (3, 29 m), transitional shrimp were predominate in the midwater pot (55 m), and only transitionals and females were captured in the lower two pots (81, 107 m). A trend of increasing size with depth was observed (Table 12).

Food habits of *Pandalus borealis* and *P. goniurus*

The frequency of occurrence of food items found in stomachs of 775

Table 11. Mean carapace length (mm) of *Pandalus borealis* captured in pots at five levels in the water column at stations AB 4 and AB 6 during the summers of 1980 and 1981. The number of shrimp measured is included in parentheses. Significance of size differences (based on size of all sexes combined) was tested by Student's t-test; non-significant differences are pointed out by brackets (]).

Pot depth	Length of Carapace (mm)(no. shrimp) Male	Transitional	Female	All sexes combined	Non-significant size difference $\alpha=0.05$
Station AB 4, 1980:					
3 m	17.4 (21)	19.9 (6)	20.5 (6)	19.2 (53)	
49 m	18.4 (47)	19.4 (15)	20.5 (44)	19.4 (106)	
95 m	18.5 (39)	19.5 (19)	20.8 (44)	19.7 (102)	
140 m	18.9 (10)	20.0 (16)	21.3 (56)	20.7 (82)	
186 m	18.0 (2)	- (0)	21.1 (18)	20.8 (20)	
			Total	19.8 (363)	
Station AB 6, 1980:					
3 m	15.3 (41)	18.4 (16)	19.4 (15)	16.8 (72)	
29 m	16.8 (73)	19.2 (22)	20.2 (45)	18.2 (141)	
55 m	17.4 (20)	18.9 (9)	19.6 (22)	18.6 (51)	
81 m	18.0 (15)	19.5 (14)	20.4 (21)	19.4 (50)	
107 m	16.9 (9)	19.2 (5)	20.1 (19)	19.0 (33)	
			Total	18.2 (347)	
Station AB 6, 1981:					
3 m	11.3 (4)*	- (0)	- (0)	11.3 (4)	
29 m	14.9 (6)	- (0)	20.8 (2)	16.4 (8)	
55 m	15.9 (173)	19.0 (35)	20.6 (38)	17.1 (246)	
81 m	17.3 (86)	19.3 (82)	20.9 (209)	19.7 (377)	
107 m	16.3 (5)	19.4 (5)	21.0 (54)	20.5 (64)	
			Total	18.8 (699)	

*includes 3 juvenile shrimp

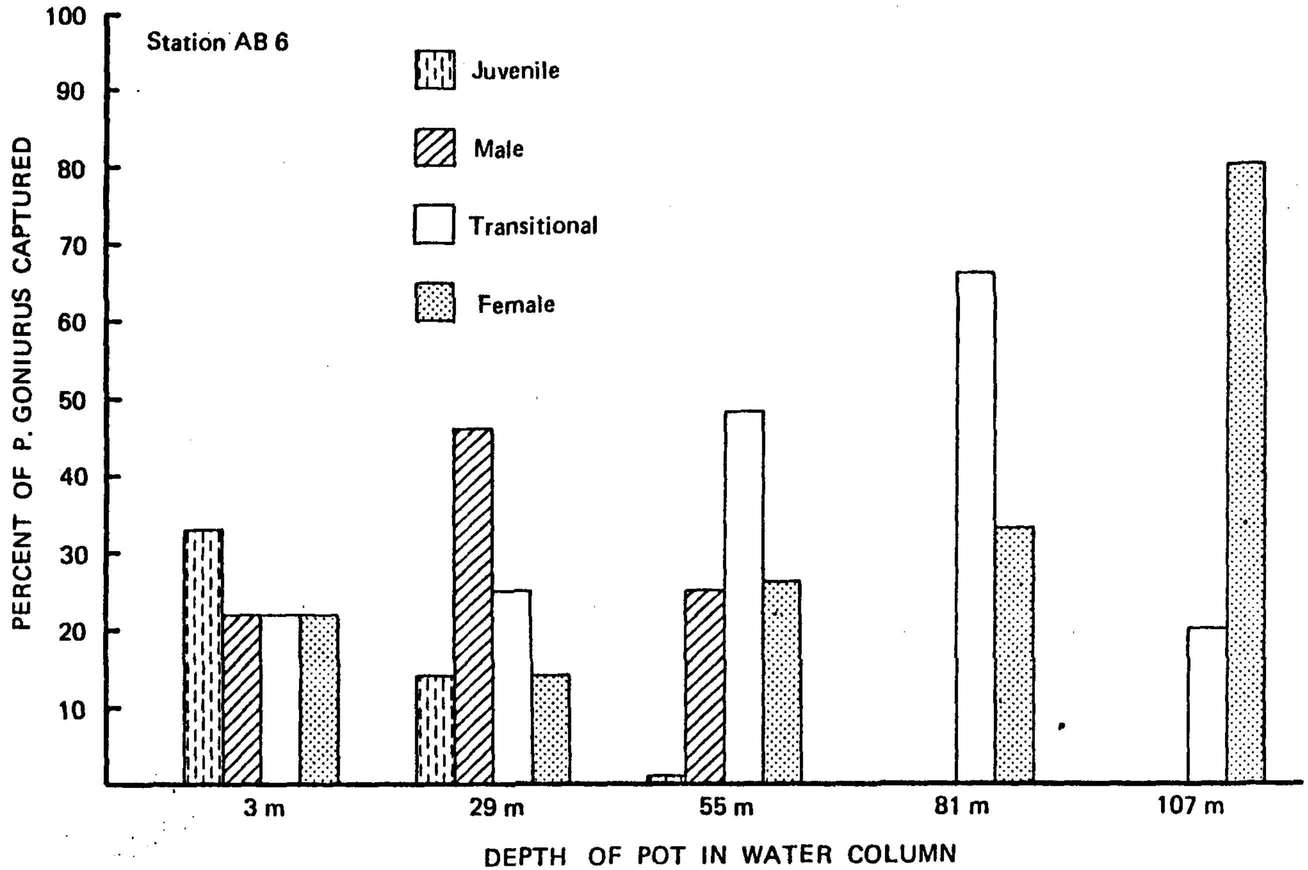

Figure 15. Distribution of *Pandalus goniurus* by sex and depth of capture in vertically suspended shrimp pots, at station AB 6 May-June 1981 (N=114).

Table 12. Mean carapace length (mm) of *Pandalus goniurus* captured in pots at five levels in the water column at station AB 6 during May and June 1981. The number of shrimp measured is included in parentheses. Significance of size differences (based on size of all sexes combined) was tested by Student's t-test; non-significant differences are pointed out by brackets (]).

	Length of Carapace (mm) (no. shrimp)					
Pot depth	Juvenile	Male	Transitional	Female	All sexes combined	Non-significant size difference α=0.05
3 m	10.7 (3)	14.0 (2)	16.0 (2)	17.7 (2)	14.1 (9)	
29 m	10.8 (4)	14.3 (13)	16.7 (7)	16.6 (4)	14.7 (28)	
55 m	13.5 (1)	15.5 (17)	16.4 (33)	17.6 (18)	16.4 (69)	
81 m	- (0)	- (0)	17.5 (2)	17.9 (1)	17.6 (3)	
107 m	- (0)	- (0)	15.8 (1)	18.0 (4)	17.6 (5)	
				Total	15.9 (114)	

Pandalus borealis captured in pots throughout the water column is summarized in Table 13. The location at which shrimp probably obtained the food items is included in Table 13. Data from stomach analysis for all stations, depths of capture and time intervals for 1980 and 1981 were combined since frequencies of most items were low and variable. A frequency of occurrence greater than 17% was recorded for only three categories: unidentifiable organic matter, sediment, and unidentifiable crustacean debris. Most stomachs (85%) contained organic matter, from a trace to more than half full. Sediment was found in most (83%) of the stomachs, and was often present even when there were no other food items. Although the sediment usually consisted of mud or sand, occasionally a rock fragment, occupying 10-25% of the stomach volume, was present. The crustacean fragments found in 61% of the stomachs consisted of spines, skeletal fragments, and fine setae. The chitinous fragments often resembled pandalid body parts. Generally, it was not possible to determine from the fragments the type of crustacean consumed. Identifiable crustaceans in stomach contents had a frequency of occurrence of 17%, and consisted of benthic and pelagic taxa. The benthic crustaceans in stomachs were ostracods, harpacticoid copepods, gammarid and stenothoid amphipods, crangonid shrimps, and other decapods. The pelagic crustaceans were calanoid and cyclopoid copepods, the amphipod *Cyphocaris challengeri*, and euphausiids. Foraminiferans, at 15% frequency of occurrence, were all benthic types. Benthic bivalves and molluskan shell fragments occurred in 10.2% of the stomachs. Pelagic mollusks, totalling 6.1%, consisted of thin-shelled pteropods, pre-settlement stage snails, and an unidentified gastropod

Table 13. The stomach contents, and location at which items were probably consumed, of *Pandalus borealis* captured in shrimp pots throughout the water column at station AB 6 and AB 4 during the summers of 1980 and 1981 (N=775).

Type of item	Number of occurrences	% frequency of occurrence	Probable location of capture
diatoms	2	0.3	unknown
filamentous algae	42	5.4	unknown
red algae	1	0.1	unknown
Spongomorpha sp.	1	0.1	unknown
Halosaccion sp./green algae	25	3.2	unknown
plant debris	7	0.9	unknown
total plants	78	10.0	
Protozoa			
Foraminifera	117	15.1	benthic
Annelida			
Polychaeta			
Melinna cristata	1	0.1	benthic
unknown polychaete	4	0.5	benthic
Arthropoda			
Crustacea			
Ostracoda	1	0.1	unknown
Amphipoda:			
stenothoid amphipods	2	0.3	benthic
gammarid amphipods	2	0.3	benthic
Cyphocaris challengeri	1	0.1	pelagic
Copepoda:			
Metridia lucens	1	0.1	pelagic
Oncaea sp.	1	0.1	pelagic
Acartia sp.	1	0.1	pelagic
calanoid copepods	16	2.1	pelagic
harpacticoid copepods	65	8.4	benthic
unknown copepods	7	0.9	unknown
Euphausiaceae	5	0.7	pelagic
Pandalidae	26	3.4	unknown
Crangonidae	1	0.1	benthic
Decapoda	2	0.3	benthic
total Crustacea	131	17.0	
unidentified crustacean fragments	472	60.9	unknown

Table 13 (continued).

Type of item	Number of occurrences	% frequency of occurrence	Probable location of capture
Mollusca			
Gastropoda:			
pre-settlement stage snail	2	0.3	pelagic
pteropods	9	1.2	pelagic
unknown pelagic gastropods	36	4.6	pelagic
Bivalvia:			
unknown bivalves	7	0.9	benthic
unidentified molluskan shell	72	9.3	unknown
total Mollusca	126	16.3	
Chaetognatha	2	0.3	pelagic
Chordata			
Teleosteii fragments	135	17.4	unknown
Unidentifiable organic matter	655	84.5	unknown
Sediment	644	83.1	benthic
Miscellaneous debris			
shell fragments	27	3.5	unknown
clear synthetic fiber	21	2.7	unknown
unknown eggs	1	0.1	unknown
feather	1	0.1	unknown

category which could have been either pteropods or snails. Diatoms, algae, and terrestrial plant debris totaled 10% frequency of occurrence. Chaetognaths and benthic polychaetes were rare items occurring at 0.3% and 0.6%, respectively. Fish fragments increased in frequency from 2.8% in 1980 to 35% in 1981. The total frequency of occurrence of food items derived from the benthos was 26% (not including 17% for fishes) and of food items obtained from the water column was 9.6%. Items identified at least to phylum, but of unknown origin, represented a frequency of occurrence of 23.7%.

Both benthic and pelagic organisms were found in stomachs of shrimp captured at all depths (Table 14). There was a slight indication of increasing occurrence of benthic organisms (e.g. polychaetes, harpacticoid copepods, decapods) with increasing depth of capture, and an increasing occurrence of pelagic organisms (e.g. pelagic copepods and gastropods) with increasing distance off the bottom. Frequency of occurrence of most items in stomachs varied greatly and demonstrated no obvious pattern with depth.

A comparison of stomach contents between *P. borealis* captured by pot, midwater trawl, vertical zooplankton tow, and otter trawl is included in Table 15. Shrimp captured by midwater trawl contained predominantly euphausiids (26%) and pelagic gastropods (15%), with a large percentage of benthic mollusks (22%) and foraminiferans (22%) as well. Stomachs of shrimp captured in a zooplankton net were for the most part full of pelagic copepods (93%). The incidence of euphausiids (11%) and pelagic gastropods (15%) was also relatively high in the net-captured shrimp, while benthic organisms occurred in low numbers

Table 14. Percent frequency of occurrence of food, shell and sediment in stomachs of *Pandalus borealis* by depth of capture in vertically suspended shrimp pots. Number of shrimp examined is in parentheses.

Depth of capture / Type of item	Percent Frequency of Occurrence 3 m (N=93)	29/49 m (N=164)	55/95 m (N=175)	81/140 m (N=241)	107/186 m (N=102)
Benthic:					
Foraminiferans	15.1	6.7	22.3	17.0	11.8
Polychaetes	1.1	0	0	0.4	2.9
Harpacticoid copepods	3.2	6.1	10.3	11.2	6.9
Benthic amphipods	0	0	0	1.2	1.0
Pandalids	1.1	0.6	2.3	6.2	4.9
Crangonids	0	0	0	0	1.0
Decapods	0	0	0	0	2.0
Bivalves and molluskan shells	22.6	7.3	9.7	10.0	4.9
Teleosteii	2.2	3.7	17.1	25.7	34.3
Sediment	72.0	85.4	84.6	85.1	82.4
Pelagic:					
Pelagic copepods	7.5	0	1.1	2.1	4.9
Pelagic amphipods	0	0.6	0	0	0
Euphausiids	0	0.6	1.7	0.4	0
Pelagic gastropods	22.6	4.9	6.9	2.5	0
Chaetognaths	0	0	0.6	0.4	0

Table 15. Frequency of occurrence of selected items found in stomachs of *Pandalus borealis* captured by four different methods.

Method of capture / Type of item	Percent Frequency of Occurrence: Pots, midwater and benthic N=775	Midwater trawl N=27	Vertical zooplankton net tow N=27	Otter trawl N=50
Benthic:				
Foraminifera	15.1	22.2	3.7	38.0
Polychaeta	0.6	0	3.7	4.0
Unknown ostracod	0.1	0	0	2.0
Harpacticoid copepod	8.4	0	7.4	2.0
Bivalves and molluskan shells	10.2	22.2	7.4	18.0
Teleosteii fragments	17.4	3.7*	18.5	4.0
Sediment	83.1	29.6	52.0	78.0
Pelagic:				
Ostracoda: *Conchoecia*	0	7.4	0	0
Calanoid copepod	2.4	0	93.0	0
Euphausiaceae	0.7	25.9	11.1	0
Pelagic gastropod	6.1	14.8	14.8	2.0
Chaetognatha	0.3	0	48.1	0
Median percent fullness	15	25	75	5

*larval fish

(3.7-7.4%), except for fish remains (19%). Shrimp captured by otter trawl showed little evidence of feeding in the water column; foraminiferans (38%) and benthic mollusks (18%) were the most common items. The pot-captured shrimp showed less dominance of any one food type. Foraminiferans (15%) were the highest frequency food item in shrimp from pots; items of benthic and pelagic origin were found. Occurrence of sediment in shrimp stomachs was highest in the pots (83%) and otter trawls (78%), decreased in the vertical tows (52%), and was quite low (30%) in the midwater trawl.

Shrimp captured above the bottom by the vertical zooplankton tows and midwater trawl had the greatest median stomach fullness with 75% and 25%, respectively (Table 15). The pot-captured shrimp had a median fullness of 15%, and the shrimp captured by otter trawl were the least full at 5%.

Food habits of 116 *Pandalus goniurus* captured throughout the water column in pots (Table 16) were slightly different than those of *P. borealis*. The frequency of occurrence of benthic foraminiferans, harpacticoid copepods, and sediment was much lower than for *P. borealis* captured in pots. Pelagic copepods and euphausiids were more common in *P. goniurus* stomachs.

Feeding activity of *Pandalus borealis* and *P. goniurus*

The median stomach fullness determined for *P. borealis* in each time interval at each depth showed variations from 5-90%, but no obvious pattern (Table 17); therefore, the data were combined across all depths (Table 18) and all time intervals (Table 19). Median stomach fullness

Table 16. The stomach contents, and location at which items were probably consumed, of *Pandalus goniurus* captured in shrimp pots throughout the water column at stations AB 6 and AB 4 during the summers of 1980 and 1981 (N=116).

Type of item	Number of occurrences	% frequency of occurrence	Probable location of capture
filamentous algae	2	1.7	unknown
Spongomorpha sp.	1	0.9	unknown
total plants	3	2.6	
Protozoa			
Foraminifera	3	2.6	benthic
Arthropoda			
Crustacea			
nauplius larvae	1	0.9	pelagic
Amphipoda:			
Metopelloides erythrophthalmus	1	0.9	unknown
Copepoda:			
Calanus sp.	1	0.9	pelagic
Centropages abdominalis	1	0.9	pelagic
calanoid copepods	6	5.2	pelagic
harpacticoid copepods	2	1.7	benthic
unidentified copepods	2	1.7	unknown
Euphausiaceae	2	1.7	pelagic
Pandalidae	1	0.9	unknown
total Crustacea	17	14.8	
unidentified crustacean fragments	59	50.9	unknown
Mollusca			
Bivalvia:			
Nuculana sp.	2	1.7	benthic
unknown pelagic gastropods	6	5.2	pelagic
unidentified molluskan shell	10	8.6	unknown
total Mollusca	18	15.5	
Chordata			
Teleosteii fragments	32	27.6	unknown
Unidentifiable organic matter	110	94.8	unknown
Sediment	58	50.0	benthic
Miscellaneous debris			
shell fragments	7	6.0	unknown
clear synthetic fiber	3	2.6	unknown

Table 17. Median percent fullness of *Pandalus borealis* stomachs from shrimp collected at five depths and during five time intervals.

Time of day	Depth of pot in water column: 29 m	55 m	81 m	107 m	Total for all depths
6-10 am	5	15	75	5	50
10 am-2 pm	5	5	15	5	5
2-6 pm	5	15	15	50	15
6-10 pm	3	15	15	75	15
10 pm-6 am	5	25	15	90	15
Total for all times	5	15	35	50	15 median of all stomachs

Table 18. Measures of feeding activity (presence of organic matter and stomach fullness) and sediment content of stomachs for *Pandalus borealis* collected by shrimp pots during the summers of 1980 and 1981 at five depths in the water column at station AB 6.

	Depth of pot in water column					
	3 m	29 m	55 m	81 m	107 m	Total
Number of *Pandalus borealis* examined	24	133	175	226	89	647
Percent of empty stomachs	0	3	4	2	0	2
Percent of feeding shrimp, i.e. 5% full and with organic matter (A)	88	53	76	83	79	74
Median stomach fullness* (B)	25	5	15	35	50	15
Calculated feeding index (A)x(B)x.(01)	22.0	2.7	11.4	29.1	39.5	11.1
Percent of stomachs containing sediment	75	82	85	86	82	84
Percent sediment by weight from combustion treatment#	76	78	77	68	87	72

*Median stomach fullness calculated from 24, 133, 202, 382, 89 stomachs examined for depths 3 m through 107 m, respectively.

#Percent sediment based on treatment of 51, 127, 206, 333, 45 stomachs for depths 3 m through 107 m, respectively.

Table 19. Measures of feeding activity (presence of organic matter and stomach fullness) and sediment content of stomachs for *Pandalus borealis* collected by shrimp pots during the summers of 1980 and 1981 throughout the water column during five time intervals at station AB 6.

	Time interval					
	1 6-10am	2 10am-2pm	3 2-6pm	4 6-10pm	5 10pm-6am	Total
Number of *Pandalus borealis* examined	115	124	150	115	143	647
Percent of empty stomachs	4	4	3	0	1	2
Percent of feeding shrimp, i.e. 5% full and with organic matter (A)	76	75	73	65	81	74
Median percent fullness* (B)	50	5	15	15	15	15
Calculated feeding index (A)x(B)x.(01)	38.0	3.8	11.0	9.8	12.2	11.1
Percent of stomachs containing sediment	85	82	77	89	87	84
Percent sediment by dry weight from combustion treatment#	67	83	79	85	73	72

*Median stomach fullness calculated from 271, 124, 150, 115, 170 stomachs examined for time intervals 1 through 5, respectively.

#Percent sediment based on treatment of 251, 117, 118, 103, 173 stomachs for time intervals 1 through 5, respectively.

for the combined data ranged from 5-50%, with an overall median of 15% (as compared to an overall mean of 35%). Feeding activity (as a function of the presence of organic matter and stomach fullness) of *P. borealis* and the presence and amount of sediment in shrimp stomachs during the summer were determined for shrimp by the five depths (Table 18) and the five time intervals (Table 19) at which they were captured. The number of empty stomachs in each group was always low (0-4%), but when the stomachs containing only sediment or traces of organic matter are also included in the non-feeding shrimp category, the percentage ranged from 12-47%. Feeding shrimp (those with stomachs more than 5% full and which contained organic matter) occurred in the groups at 53-88%.

The feeding index used combines the percent feeding shrimp and the median stomach fullness to amplify the differences in feeding activity between groups. A relatively high feeding index was calculated for the 3 m group of shrimp (Table 18). The lowest feeding index was calculated for the 29 m level, and values increased with depth to a maximum on the bottom (107 m). The feeding indices calculated for different time intervals (Table 19) suggest that feeding activity was lowest during mid-day (10 am-2 pm), increased in the evening (6-10 pm) and afternoon (2-6 pm), and was highest during the dark hours (10 pm-6 am) and early morning (6-10 am).

The percent feeding shrimp was generally greater within each depth or time group for *P. goniurus* than for *P. borealis* (Tables 18-20). The feeding index calculated for all *P. goniurus* combined was similar (feeding index=13) to that calculated for all *P. borealis* combined

Table 20. Measures of feeding activity (stomach fullness and presence of organic material) and sediment content of stomachs for *Pandalus goniurus* collected by shrimp pots during the summer of 1981 at five depths in the water column and during five time intervals.

	Depth of pot					Time of capture					
	3 m	29 m	55 m	81 m	107 m	6-10am	10am-2pm	2-6pm	6-10pm	10pm-6am	Total
Number of *Pandalus goniurus* examined	9	28	41	1	5	2	9	48	3	22	84
Percent of empty stomachs	0	0	5	0	0	0	0		0	0	2
Percent of feeding shrimp (A)	100	93	76	100	100	100	78	81	100	95	86
Median percent stomach fullness (B)	100	15	15	50	100	38	15	15	100	15	15
Calculated feeding index (A)x(B)x.(01)	100	14	11	50	100	38	12	12	100	14	13
Percent of stomachs containing sediment	33	50	49	100	60	100	78	52	33	27	49

(feeding index=11) since the overall median stomach fullness was the same.

Sediment in stomach contents of *Pandalus borealis* and *P. goniurus*

The number of *Pandalus borealis* stomachs containing sediment varied only slightly between groups (Tables 18 and 19). The range was 82-89% except for a decrease to 77% in the mid-day (2-6 pm) catch, and 75% in the 3 m catch. A smaller percentage (49%) of *P. goniurus* (Table 20) stomachs contained sediment than the *P. borealis* stomachs (84%) examined.

Percent dry weight sediment values for *P. borealis* stomach contents were greatest for the bottom (107 m) samples (mean=87%) (Table 18). Fluctuations in sediment dry weight by time ranged from 67-85% (Table 19). The raw data and results of a two-way median polish on *P. borealis* stomach sediment dry weight values are included in Table 21. The column effects (depth) show that the percentage of sediment in stomachs increased with depth, while the row effects (time) demonstrate fluctuations throughout the day and night.

Table 21. Raw data (mean percent dry weight) and residuals from two-way median polish on sediment content of stomachs for *Pandalus borealis* collected in pots at each of five depths and five time intervals. Row effects (time) and column effects (depth) show the departure from the overall median for each group. Residuals in the table indicate departures not accounted for by row and column effects.

	Raw data:				Residuals:				
Depth of pot / Time of day	29 m	55 m	81 m	107 m	29 m	55 m	81 m	107 m	row effect (time)
6-10am	73	74	66	96	0	0	-13	16	0
10am-2pm	73	80	84	95	-5.5	0.5	-0.5	9.5	5.5
2-6pm	73	74	80	80	0	0	1	0	0
6-10pm	89	85	83	84	8.5	3.5	-3.5	-3.5	7.5
10pm-6am	78	71	78	75	7	-1	1	-3	-2
				column effect (depth)	-3.5	-2.5	2.5	3.5	76.5 median of all stomachs

DISCUSSION

The physical environment

Deepwater renewal in Aialik Bay probably occurs during late winter (Muench and Heggie 1976, Dave Nebert, personal communication). Oxygen data from Aialik Bay suggests that deepwater renewal occurs at least annually; there is no evidence that bottom water approaches anoxic conditions (IMS unpublished data, this study). Density profiles inside and outside the sill during summer show that water of greater density is available outside the sill at other times than late winter. Renewal of water inside the basin at mid-depths could occur year-round as a result of denser water outside being carried over the sill at flood tide. Advection of outside water over the sill by tidal action provides a means of vertically mixing water near sill depth and introducing planktonic organisms into the upper bay. Although data were not collected close enough to Aialik Glacier to detect upwelling of glacial meltwater, it is expected that the cool, fresh water would be masked by runoff from the two meltwater streams during summer.

Surface-water turbidity recorded for Aialik Bay (Secchi disc depths of 0.2-5.0 m) was typical of glacial fjords. Secchi disc depths of one meter or less are reported for the head of several inlets with glacial runoff in southeastern Alaska (Pickard 1967). Pickard (1967) attributes a decrease in suspended load in the seaward direction to sinking of silt and flocculation of particles as salinity increases. The increase in Secchi depths to 2-5 m near the sill of Aialik Bay was similar to the increased Secchi depths in the head of the southeastern fjords.

The decrease in Secchi depth during high tide at station AB 4 was probably due to accumulation of turbid surface water at the head of the bay. During tidal ebb, surface water flows out and mixes with more saline water. Flocculation and sinking of particles then decreases turbidity. A decrease in suspended load by flocculation and sinking of particles with depth and distance from the glacier was also suggested by the vertical profiles of suspended sediment load.

Zooplankton

The zooplankters in upper Aialik Bay were primarily those which spend all or a portion of their life in the upper water column. The small, surface dwelling, coastal copepods such as *Pseudocalanus* sp., *Oithona similis*, and *Acartia longiremis* (Damkaer 1977) numerically dominated the zooplankton community. *Metridia lucens*, a diel migrating species (Damkaer 1977), appeared in large numbers. *Metridia okhotensis*, also a diel migrator (Vinogradov and Arashkevich 1969), occurred in smaller numbers. All of these species could be swept into the upper bay at flood tide as outside water is carried over the 10 m sill. Introduction of planktonic organisms into the upper bay by water advected over the sill was also suggested by the high plankton species richness at station AB 4 just inside the sill and by the sporadic occurrence of offshore and deepwater species at the inner stations.

The region close to the glacier (AB 1) differed from the region just inside the sill (AB 4) in distribution of zooplankton biomass. Zooplankton was distributed throughout the water column near the glacier, apparently in response to reduced light. Near the sill, zooplankton followed the usual pattern of diel migration and were concentrated in deep water (below 100 m) during daylight. The glacier-front region also showed reduced biomass, reduced diversity and abundance of planktonic taxa, and increased dominance of small copepods compared to the number of large copepods. The high suspended load and low salinity in the glacier-front region may limit the number of organisms able to survive there. Primary production was probably reduced by the turbidity of the surface water as well. Several of the larger copepods (*Metridia* spp., *Calanus* spp.) which migrate to deep water on a daily or seasonal basis would be restricted by the shallow depths (100 m or less) close to the glacier. Large copepods were more common at the deeper station (AB 4, 186 m) where more vertical migration could occur.

The zooplankton biomass data may not be representative of actual values because of differences in sampling depths. Vertical tows from 150 m at station AB 8 (155 m) probably sampled the entire water column, whereas 150 m tows at stations AB 4 (186 m) and AB 9 (260 m), and 50 m tows at stations AB 1 (75 m) and AB 6 (107 m), were well off the bottom. Although examination of the vertical distribution of zooplankton was only cursory, the results demonstrate that, especially at station AB 4, a large part of the biomass was present in the lower water column during the daylight period. Therefore, biomass data from vertical tows which failed to sample the lower 25-50 m of the water column probably do not represent the total zooplankton biomass.

The benthic environment and organisms

The characteristics of the sediment and composition of benthic organisms near Aialik Glacier demonstrated the effects of the high sediment load from glacial meltwater. High sedimentation rate (0.3 m/yr) (Post 1980) and low primary production (Goering et al. 1973) in the region of the glacial sediment plume are presumably responsible for the decreased nitrogen and organic carbon in the sediment. The low sediment organic content near the glacier also appeared to be one of the limiting factors for benthic organisms there. However, a few taxa present near the glacier (the polychaetes *Melinna cristata, Nephtys punctata*; the bivalve mollusks *Axinopsida viridis, Nuculana* sp.) were abundant. All of the other taxa present were rare. The number of taxa increased, and a trend of greater number of taxa at lower densities occurred as sedimentation rates decreased and organic content of the sediment increased with increasing distance from the glacier.

Differences in distribution of taxa between stations inside and the station outside the sill were evident from the plots of taxa in geometric abundance classes. Inside stations showed an increased number of taxa in higher geometric abundance classes (higher dominance of taxa) than the outside station. In addition, taxa which were common in the upper bay tended to be less common or absent at the station outside the sill while numerous additional taxa occurred at the outside station. Number and types of benthic taxa in Aialik Bay were similar to those found in other glacial fjords in Alaska. Blue Fjord (turbid outwash) and Derickson Bay (tidewater glacier) in Prince William Sound had about 15-30 taxa at each station, including *Nephtys punctata, Onuphis* *iridescens, Lumbrineris* spp., *Praxillella gracilis, Myriochele heeri, Nucula tenuis, Axinopsida serricata,* and *Eudorella emarginata* (Hoskin 1977), taxa also common in Aialik Bay. The number of taxa and densities of benthic organisms are more reduced in turbid outwash fjords than tidewater-glacier fjords although many of the same taxa occur in both (e.g. Resurrection Bay near Bear Glacier, Feder et al. 1979; Port Valdez, Feder et al. 1982). Biomass of benthic organisms in Aialik Bay also seemed to be higher than in turbid outwash fjords (Hoskin 1977, Feder et al. 1982), but was much lower (approximately one tenth) than benthic biomass of the Alaskan coastal shelf (Feder and Matheke 1980) or Cook Inlet (Feder et al. 1980).

The density and diversity of benthic organisms just inside the sill (AB 4), suggests that conditions were more favorable and stable there than at other stations in the upper bay. Abundance of organisms was also higher inside the sill (AB 4) than outside the sill (AB 9). A large part of the glacial suspended sediment load is deposited near the glacier and sedimentation is reduced near the sill (Post 1980). Stress on benthic organisms from high sedimentation rates, is therefore, also reduced near the sill. The inner basin behind the sill is a stable environment undergoing deepwater renewal at least annually (Muench and Heggie 1976) and probably receives organic debris and organisms from over the sill with incoming water at flood tide. Terrestrial debris also accumulates in the deepest part of the steep-walled inner basin. Pearson (1975) suggests that a moderate increase in organic input increases the food supply and results in an increased abundance of benthic organisms. The increased abundance and diversity of benthic organisms in the deep, stable basin adjacent to the sill relative to the glacier-front region, presumably as a result of accumulation of organic matter there.

Distribution and migration of pandalid shrimps

The five species of pandalid shrimps present in Aialik Bay and their relative abundances were typical of Alaskan waters (Table 22). In Aialik Bay, as in other coastal waters, *Pandalus borealis* was the dominant species collected by trawl and pots, followed in number by *P. goniurus* and *P. hypsinotus*, *P. platyceros* was rare, and *Pandalopsis dispar* was common but captured only by trawl (Barr and McBride 1967, Barr 1970, Feder and Jewett 1977, McLean et al. 1977). The infrequent occurrence of *P. platyceros* from areas with muddy sediments, such as Aialik Bay, is expected since the shrimp occurs most commonly on rocky substrates (Butler 1980).

The number of shrimps collected by trawl in Cook Inlet, Prince William Sound, and Resurrection Bay was similar to that taken in Aialik Bay (Feder and Paul 1977, Feder et al. 1979, Feder and Paul 1981, Feder et al. 1982). However, trawl collections in Alitak and Ugak Bays of Kodiak Island, regions of importance in the shrimp fishery here, generally contained greater numbers of pandalid shrimps than in Aialik Bay (Feder and Jewett 1977).

Although surveys of epibenthic organisms by large trawl provide qualitative comparisons between sampling sites and times, the number of shrimps captured by small otter trawl may vary by as much as two orders of magnitude for similar locations and dates (Table 22: see trawl data

Table 22. Selected data on the number of pandalid shrimps captured and percent ovigerous shrimp from benthic trawls in Alaska fjords.

Location of trawl	Date	Gear	Depth of trawl (meters)	Distance fished (km)	Time fished (min.)	Species	Number captured	Number per km	Percent ovigerous
[a]Alitak Bay, Kodiak Is.	6-8/76 3/77	EOT	-	1.62 (160 total)	30	*P. borealis*	825*	510	some in August and March
						P. goniurus	334*	207	
						P. hypsinotus	460*	284	
						P. dispar	31*	19.3	
[a]Ugak Bay, Kodiak Is.	6-8/76 3/77	EOT	-	1.68 (165 total)	30	*P. borealis*	931*	553	some in August and March
						P. goniurus	272*	162	
						P. hypsinotus	259*	153	
						P. dispar	3.4	2.1	
[b]Cook Inlet 5A	10/27/76	AGT	182	2.78	45	*P. borealis*	201	72.3	some
						P. dispar	1	0.4	some
[b]Cook Inlet 8A	10/28/76	AGT	110	0.93	15	*P. borealis*	24	25.8	nc
[c]Unakwik 3	3/4/73	SOT	300	-	15	*P. borealis*	79	-	2.5
						P. dispar	411	-	4.1
[c]Columbia Bay 2	12/10/73	SOT	75	-	30	*P. borealis*	780	-	66#
						P. hypsinotus	79	-	87
						P. platyceros	1	-	nc
[d]Port Etches 1	10/3/73	SOT	64	-	15	*P. borealis*	1254	-	1.1
						P. goniurus	2	-	0
						P. hypsinotus	125	-	3.2

Table 22 (continued).

Location of trawl	Date	Gear	Depth of trawl (meters)	Distance fished (km)
[d]Port Valdez 62	9/3/81	SOT	232	2.26
[d]Port Valdez 43	9/3/81	SOT	232	1.7
[e]Resurrection Bay R-2	11/28/77	SOT	168	-
[e]Resurrection Bay R-2.5A	11/28/77	SOT	278	-
[e]Resurrection Bay R-2.5	4/24/78	SOT	285	-
[e]Aialik Bay A-22 (AB 4)	12/1/77	SOT	189	-
[e]Aialik Bay A-23 (AB 9)	12/1/77	SOT	260	-
[f]Aialik Bay AB 3	12/4/79	SOT	140	2.9

Time fished (min.)	Species	Number captured	Number per km	Percent ovigerous
15	*P. borealis*	15	6.6	0
	P. dispar	18	8.0	0
-	*P. borealis*	164	96.5	0
	P. dispar	120	70.6	1.7
10	*P. borealis*	5	-	8.0
	P. dispar	5	-	0
10	*P. borealis*	400	-	50
	P. dispar	200	-	24
10	*P. borealis*	1300	-	0
	P. dispar	71	-	0
10	*P. borealis*	840	-	0.1
	P. hypsinotus	19	-	5.3
	P. dispar	26	-	11.5
10	*P. borealis*	8	-	100
	P. dispar	13	-	69
20	*P. borealis*	782	270	24.3
	P. goniurus	447	154	66.2
	P. hypsinotus	11	3.8	27.3
	P. platyceros	1	0.34	0
	P. dispar	116	40	15.5

Table 22 (continued).

Location of trawl	Date	Gear	Depth of trawl (meters)	Distance fished (km)	Time fished (min.)	Species	Number captured	Number per km	Percent ovigerous
[f]Aialik Bay AB 5	6/11/80	SOT	80-96	4.5	15	*P. borealis*	300	66.7	0
						P. goniurus	60	13.3	0
						P. hypsinotus	80	17.8	0
						P. dispar	20	4.4	0
[f]Aialik Bay AB 4-5	12/3/80	SOT	192	5.9	30	*P. borealis*	221	37.5	4.1
						P. hypsinotus	1	0.17	0
						P. dispar	12	2.03	50
[f]Aialik Bay AB 5	12/3/80	SOT	140	3.85	15	*P. borealis*	2008	521.6	7.4
						P. goniurus	26	6.8	11.5
						P. hypsinotus	17	4.4	17.7
						P. dispar	65	16.9	35.4

[a]Feder and Jewett 1977

[b]Feder and Paul 1981

[c]Feder and Paul 1977

[d]Feder et al. 1982

[e]Feder et al. 1979

[f]This study

EOT = Eastern otter trawl

AGT = Agassiz trawl

SOT = Small otter trawl

nc = no comment

*averaged values for 99 and 98 trawls in Alitak and Ugak Bays, respectively

#percent ovigerous from a repetative trawl at the same time and location from Port Valdez stations 43 and 62). Seasonal migration of *P. borealis* results in widely dispersed populations during the summer and dense populations in restricted areas during the winter (Ivanov 1970). Diel vertical migrations of *P. borealis* and *P. jordani* also causes decreases in night-time benthic catches (Tegelberg and Smith 1957, Barr 1970, Pearcy 1972, Beardsley 1973). Both types of migration by shrimps affect the variation in number captured at a particular location, and probably account for many of the differences observed in trawl catches in Alaskan bays (Table 22: see trawls from Resurrection Bay R2.5A on 11/27/77 and R2.5 on 4/24/78, and Aialik Bay AB 5 on 6/11/80 and AB 5 on 12/3/80). Yearly variation in the population densities due to poor recruitment of young, natural mortality, and over-fishing also account for the fluctuations in trawl collections. Wide variation in the percentage of pandalids carrying eggs were observed in Aialik Bay and reported for pandalids in other Alaskan waters (Table 22). Recovery of a population of shrimp in an isolated fjord following poor recruitment or high adult mortality may be slower than other areas because of restriction of recruitment from outside populations by the shallow sill.

Many crustaceans are known to respond to changes in light intensity with diel migrations (Bainbridge 1961). Vertical migration of pandalid shrimps, apparently a response to changing light intensity (Barr 1970, Beardsley 1973), begins late in larval development (Rothlisberg and Pearcy 1976). Suggested advantages gained by migratory behavior include continuing association of shrimps near vertically migrating prey (zooplankton) (Barr 1970, Pearcy 1970, Beardsley 1973), avoidance of predators (Pearcy 1970, Beardsley 1973), and dispersal of shrimp populations (Pearcy 1970). Data for vertical migration of shrimps in Aialik Bay support the hypothesis that shrimps respond to reduced light intensity beneath the turbid surface water of the upper bay. *Pandalus borealis* and *P. goniurus* were distributed throughout the water column (up to 80-130 m off the bottom) in mid-summer, at all times of the day, and on sunny or cloudy days. This distribution contrasts with studies in which shrimps were captured at mid-depth or higher in the water column only at night (Barr 1970), on cloudy days (Beardsley 1973), and for short periods of time during summer nights (Barr 1970). At the head of Aialik Bay (AB 6), zooplankton was also distributed throughout the water column during daylight, suggesting that these organisms as well as shrimps responded to the reduced light intensity beneath the turbid surface water layer.

Vertical migration was observed for all sexes of *P. borealis* and *P. goniurus* in Aialik Bay, although there was a tendency for smaller (juvenile or male) shrimps to occur higher in the water column. The greater proportion of younger shrimp in the upper water column in Aialik Bay supports the hypothesis that vertical migratory behavior is a relic of a behavior acquired in the larval phase (Rothlisberg and Pearcy 1976).

The role of vertical migration as a dispersal mechanism for pandalid shrimps is important in a fjord with a shallow sill. Introduction of organisms into the upper bay requires that they swim, creep, or be carried over the sill at a depth of no more than ten meters. Diel vertical migration of young or adult shrimps places them in a position to be carried over the sill with incoming water at flood tide. A majority of the shrimps which occurred in the upper water column, and could be swept over the sill, were immature or young males. Therefore, shrimps which are most likely to be recruited from an outside population will not become breeding females for another year or more. Shrimps could also be carried over the sill in the surface outflow at ebb tide, but relatively few shrimps occur in the surface few meters where most outflow takes place. A net increase in numbers should occur with time as the shrimps mature and their migrations become restricted to deeper water below sill depth.

Food habits of pandalid shrimps

Pandalid shrimps are opportunistic feeders and consume a variety of pelagic and benthic plants and animals, including small organisms or fragments of large organisms (Table 23). Food organisms in stomachs of *P. borealis* collected in pots in Aialik Bay included crustaceans (17%), mollusks (16%), foraminiferans (15%), plant material (10%), and polychaetes (0.6%). Fish fragments occurred at 17% frequency of occurrence, but may be overestimated because of feeding on the bait in the pot. Crustacean fragments (61%), sediment (83%), and unidentifiable organic matter (85%) were common in shrimp stomachs, but gave little information about the food source. Identifiable food items from the benthos totaled 26% frequency of occurrence, and from the water column, 9.6%.

Collection of shrimp from several locations and depths within Aialik Bay permitted a comparison of food utilized by shrimps in

Table 23. Selected data from pandalid shrimp feeding
benthic trawl unless otherwise specified.

Reference	Species	Location of capture
Feder and Jewett 1981	*P. borealis*	Kodiak, AK
Crow 1977	*P. borealis* *P. hypsinotus* *P. dispar*	Kachemak Bay, AK
Berkeley 1929	*P. danae* *P. borealis* *P. hypsinotus* *P. dispar* *P. platyceros*	Vancouver, BC
Warren and Sheldon 1967	*P. montagui*	estuary of river Thames, England

studies. All specimens were collected by

Number of specimens	Stomach contents
1300	Shrimp from bays: sediment, diatoms (centric or pennate), crustacean remains (shrimp, decapod, unidentified crustaceans, occasional ostracods, harpacticoids, amphipods, *Balanus* spp., possibly shrimp molts), polychaetes (Capitellidae and Spionidae). Shrimp from the outer shelf: crustacean remains, bivalves (*Nucula*, *Yoldia*, *Axinopsida*), fish bones and scales.
70	Amorphous organics, invertebrate parts (shrimp, copepods, crabs, clams), macroalgae (*Fucus*, *Porphyra*, *Ulva*, *Bangia*), filamentous algae, diatoms.
50 50 50 50 50	Only two with vegetable matter (seaweed), marine worms, small crustaceans.
several 100	Food and sand taken in constant proportion, 50% of sand remains after 8-10 hours, 20% after 16 hours, 10% after 27 hours.

Table 23 (continued).

Reference	Species	Location of capture
Pearcy 1970	*P. jordani*	Oregon coast
Rice, et al 1980	*P. borealis*	Cook Inlet, AK
	P. goniurus	
	P. hypsinotus	
Allen 1963	*P. montagui*	Northumberland, England

Number of specimens	Stomach contents
129 and 58	Isaac-Kidd trawl: Euphausiids 50%, copepods 15%, fish scales, chaetognaths, shrimps, amphipods, eggs, polychaetes, sediment; 48/129 empty. Bottom trawl: unidentifiable soft material, sand, shell fragments, polychaetes, rarely crustacean debris.
233	Benthic crustaceans 57%, polychaetes 26%, diatoms 20%, decapod 6%, ostracod 4%, spionid 6%, Nephtyidae 3%, *Lumbrineris* 3%, bivalves 19%, *Nucula tenuis* 6%, *Nuculana* 4%, foraminiferans 17%, fish 6%, plant 3%, sediment 54%.
241	Benthic crustaceans 34%, polychaetes 13%, bivalves 8% (decapod, ostracod, amphipod; Maldanid; *Nucula*) foraminiferans, plants, diatoms, sediment 74%.
195	Benthic crustaceans 60%, polychaetes 48%, bivalves 11% (decapods; *Disoma*, Polynoids, Spionids; *Nucula tenuis*) fish, sponge, diatoms, plants, foraminiferans, sediment 71%
200	Annelids 51% (*Pectinaria*, small polychaetes), crustaceans 33% (amphipods, *Pandalus* zoea), hydroids 0.8%, sediment in all, foraminiferans 4.3%, fish scales 2.6%, unknown 8.6%, 68% with food in stomach.

Table 23 (continued).

Reference	Species	Location of capture
Turpaeva 1953	*P. borealis*	Northern seas of the U.S.S.R.
Mistakidis 1957	*P. montagui*	estuary of Crouch and Thames, England
Butler 1970	*P. platyceros*	Vancouver, B.C.
Dahlstrom 1970	*P. jordani*	Northern California
Horsted and Smidt 1956	*P. borealis*	Greenland

Number of specimens	Stomach contents
45	Detritus 60% (polychaete setae, crustacean chitin, foraminiferan shells, diatoms, tintinids, peridiniums), planktonic copepods 30% (mostly *Calanus finmarchicus*) and harpacticoids, 10% with large sand grains.
650	Polychaetes 66-84%, Sabellaria 29-52%, crustaceans, lamellibranchs, hydroids, gammarid amphipods, crangons, hyppolytids, pandalids, copepods, *Balanus* cyprid larvae, *Mytilus* larvae, foraminiferans.
24	Crustacea (unidentified crustaceans and amphipods), polychaetes (Sabellaridae, *Pallasia* sp., Polynoidae, *Nephtys*, Maldanidae), fish scales, sponge spicules.
	Large amount of mud, polychaetes, porifera, diatoms, amphipods, isopods.
?	Mostly crustacean debris, mainly *Boreomysis*, polychaete setae, foraminiferans, radiolarians, fecal pellets, fine sand, a significant amount of food from the water column.

Table 23 (continued).

Reference	Species	Location of capture
Barsukov and Ivanov 1979	*P. borealis*	Anastasia Bay, U.S.S.R.
Barr 1970	*P. borealis*	Kachemak Bay, AK

Number of specimens	Stomach contents
?	Isaac-Kidd Trawl: Euphausiids, planktonic organisms.
?	Bottom and midwater shrimp pots: Brachyuran crab larvae.

different habitats. *Pandalus borealis* collected by vertical net tow and midwater trawl contained high percentages of euphausiids (46%) and pelagic copepods (19%), while those collected by bottom trawl contained mostly benthic organisms (foraminiferans=38%, mollusks = 18%). *Pandalus goniurus* captured in greater numbers in the upper water colum than near the bottom, demonstrated greater use of pelagic food resources than *P. borealis*. The comparison suggests that shrimps, for the most part, eat what is most readily available. Pearcy (1970) found that *P. jordani* collected in midwater had primarily eaten copepods and euphausiids while *P. jordani* collected on the bottom primarily contained unidentifiable soft material, sand, and shell fragments. Other feeding studies (Table 23) also demonstrate a relationship between the location in the water column at which shrimps were captured, and the type of material found in the stomachs (e.g. Barr 1970, Barsukov and Ivanov 1979, Rice et al. 1979). The high frequency of occurrence of euphausiids and copepods in stomach contents of 54 *P. borealis* captured by midwater trawl and vertical net tow suggests that shrimps fed during vertical migration. However, 673 *P. borealis* from midwater pots, with 10.3% frequency of occurrence of pelagic organisms, showed much less use of pelagic food resources. The type of food items found in stomachs of shrimps from pot collections and stomach fullness values suggest that more feeding occurred deep in the water column and at the bottom than in the upper water column. Feeding in the water column during diel migration may occasionally be important to a few shrimps, but did not appear to be a principal means of obtaining food for the population as a whole.

Shrimps captured in midwater had large amounts of sediment in their stomachs. It is assumed that all sediment in stomachs of shrimps was obtained from the bottom since sediment particles would be functionally difficult for shrimps to obtain in the water column. Warren and Sheldon (1967) determined that *P. montagui* regurgitated sand and other large undigestible particles. Fifty percent of the sand consumed was lost after 8-10 hours and only 10% remained after 27 hours. *Pandalus borealis* in Aialik Bay demonstrated a decrease in percent sediment and stomach fullness with distance off the bottom, suggesting that less feeding and more regurgitation of sediment occurred as the shrimps swam upwards. The feeding data for pandalid shrimps in Aialik Bay in terms of mean stomach fullness, percentage of empty stomachs, and the amount of inorganic sediment in stomachs is similar to that reported in other studies (Table 23). Turpaeva (1953) reported a mean stomach fullness of 28% for 45 *P. borealis* examined from Russian waters. The mean stomach fullness for *P. borealis* from Aialik Bay was 35% (median=15%). The percentage of empty stomachs for this species was reported as 18% by Rice et al. (1980) and 32-41% for *P. montagui* by Mistakidis (1957). In the present study, 2.8% of *P. borealis* stomachs were completely empty, but 26% contained only sediment or trace amounts of organic matter. Sediment is mentioned in several of the food studies, but seldom measured (Table 23). Turpaeva (1953) found that 10% of *P. borealis* stomachs contained large sand grains. Rice et al. (1980) report 54% of *P. borealis* stomachs contained sediment, and sediment averaged 60% by dry weight (carbonates removed) of stomach contents. Sediment was found in 83% of the *P. borealis* examined from Aialik Bay and was 76% by dry weight (carbonates included) of stomach contents. In general, pandalid shrimps are characterized by low mean stomach fullness, a large number of stomachs with only sediment or trace amounts of organic matter, and a large amount of sediment in the stomachs. Sediment bacterial carbon or dissolved carbon within sediments were suggested to be potential energy sources for panaeid (Moriarty 1978) and crangonid (Rice 1980) shrimps. The role of bacterial carbon in the diet of pandalid shrimps is unknown.

Several problems with the methods of determining food habits became evident during collection and examination of shrimps for the present study: 1. The use of baited shrimp pots may primarily attract shrimps which have not recently fed, thereby biasing the estimate of stomach fullness for the population. 2. The presence of bait may induce shrimps to occur and feed at a location or time in which such activities might not usually take place. 3. Although efforts were made to ensure that fish used as bait was physically inaccessible to the shrimps, the high frequency of occurrence of fish fragments in shrimp stomachs in 1981 suggests that they were able to reach the bait. 4. Stomach contents for shrimps captured in zooplankton net tows may be biased. Planktonic animals collected by the net would be concentrated and more readily captured by the shrimps in the net than in the water column. However, many prey items were well digested before the shrimps were fixed, suggesting that they consumed some zooplankton prior to their collection in the net. 5. Shrimps in pots would not be able to feed normally, but would continue to digest the food obtained prior to entry. Apparent stomach fullness would, therefore, decrease. 6. Digestion of the chewed and torn fragments of food items in stomachs made identification difficult, and resulted in a high frequency of occurrence in categories such as "unknown crustacean fragments" and "unidentifiable organic matter". 7. A part of the 61% of stomachs containing "crustacean fragments" was probably due to cannibalism while shrimps were crowded in the pots. Partially eaten shrimps were occasionally found with live shrimps in a pot. The occurrence of chitinous crustacean fragments may also be attributed in part to consumption of molts (Feder and Jewett 1981). 8. Loss of consumed food by regurgitation when shrimps were immersed in formalin biased fullness estimates. Shrimps from a sample known to have a high percentage of full stomachs, as viewed through the carapace when initially collected, often contained little or no material when examined later in the laboratory. Some shrimps with nearly empty stomachs had a food mass in the mouth region.

Despite problems with sampling and analysis, examination of pandalid shrimps and their food habits in Aialik Bay provided valuable information about the types and abundance of organisms fed upon by shrimps there. Shrimps apparently eat whatever food is available to them. No food item dominated the stomach contents of *P. borealis* in Aialik Bay, and a wide spectrum of items was typically found in individual shrimp stomachs. There was little evidence that shrimps ate polychaetes, the most abundant group of organisms collected from the bottom by van Veen grab. Available data suggest that neither pelagic nor benthic environments provided a rich food resource for pandalid shrimps in Aialik Bay.

Food may be a limiting factor for *P. borealis* at the glacier front (AB 6). Shrimps from all depths at station AB 6 were smaller at maturity than *P. borealis* at station AB 4. Benthic organisms were sparse in the glacier-front region, and feeding opportunities for pandalid shrimps on the bottom would be limited. The zooplankton in the glacier-front region was dominated by small copepods which would be difficult for shrimps to capture in midwater. Although the extent of food limitation and the effect of this limitation on shrimp populations are not known, smaller size and reduced abundance of shrimps were observed in the glacier-front region relative to the region just inside the sill.

SUMMARY AND CONCLUSIONS

The species composition, abundance, and behavior of organisms within Aialik Bay, a tidewater-glacier fjord, reflect the effects of environmental conditions there. Three features which are important in distinguishing organisms of Aialik Bay from those in other coastal embayments are the high suspended sediment load, the shallow sill, and icebergs calving off the glacier face. The high suspended sediment load reduces the diversity and abundance of pelagic and benthic organisms present and greatly reduces light in the water column, which results in altered diel migration patterns of crustaceans. The shallow sill restricts the exchange of water and acts as a trap for organisms and detritus. Icebergs calved from the glacier front cause turbulence and serve as haulout sites for harbor seals in the fjord. Some of the effects and results of environmental conditions in a tidewater-glacier fjord were clarified by examination of the distribution, migration, and food habits of pandalid shrimps, and relevant environmental parameters.

Pandalus borealis and *P. goniurus* remained in the upper water column throughout the day and night in upper Aialik Bay. This behavior is in contrast to that reported for pandalids at other locations, where shrimps returned to near or at the bottom during daylight. A greater number of *P. borealis* were captured in midwater pots in upper Aialik Bay than on the bottom at all sampling periods. Shrimps were collected in surface pots (3 m) only during the evening or night. The pattern of distribution and migration of *P. borealis* and *P. goniurus* suggests that reduced light intensity in the upper bay results in shrimps, as well as zooplankters, remaining in midwater throughout the day and night. The proportion of juvenile and male shrimps captured in pots increased with distance off the bottom, suggesting that diel vertical migration is a behavior acquired early in life and that shrimps migrate less as they age and become females. Although vertical migration of *P. borealis* does not appear to be important as a foraging strategy in Aialik Bay, it probably is important as a dispersal mechanism. Prolonged migration into the upper water column in the outer bay would increase the opportunities for shrimps to be swept over the shallow sill and into the upper bay.

Pandalid shrimps are opportunistic feeders in upper Aialik Bay, and appear to feed more at the bottom and in the lower water column than in midwater or surface layers. The most common items found in stomachs of *P. borealis* were unidentifiable organic matter (84.5%), sediment (83.1%), crustacean fragments (60.9%), identified crustaceans (16.9%), mollusks (16.3%), foraminiferans (15.1%), and plant material (10.0%). Stomach contents of *P. goniurus* were similar to those of *P. borealis*. The wide variety of food items found in shrimp stomachs suggests that there is no abundant and readily accessible food source in Aialik Bay.

Neither pelagic nor benthic organisms were found to be unusually abundant in upper Aialik Bay. In fact, the region closest to the glacier (within 3 km) was characterized by a low abundance of pelagic organisms and few benthic organisms relative to the rest of the bay. Zooplankters in the glacier-front region were primarily small, surface-dwelling coastal copepods and chaetognaths. A few kilometers down the fjord from the glacier front, just inside the sill, a greater diversity (abundance and species richness) of zooplankton was present, including several large copepods. The difference between the two regions suggests that 1. zooplankters are brought into the upper bay over the 10 m sill on flood tide and accumulate behind the sill after sinking, and 2. the less severe environmental conditions (higher salinity, reduced suspended load) away from the glacier permit more species and individuals to survive further down the fjord. The regions of low sediment organics near the glacier also supported few benthic organisms. Sediment organics, number of taxa, and diversity of organisms increased with distance from the glacier. Higher abundance and diversity of benthic organisms in the deep basin inside the sill appears to be related to increased organic input and reduced sedimentation rates there. The lack of readily accessible food throughout the upper bay results in shrimps using a variety of food resources.

The pelagic and benthic foods available for pandalid shrimps in Aialik Bay are sufficient to support populations within the range of abundances described for these crustaceans in other coastal bays of Alaska. Pandalids have been fished by commercial trawlers in Aialik Bay in the past, but present abundances are not sufficiently high to make fishing by trawl economically feasible (local fishermen, personal communication 1980). However, pot fishing for *Pandalus hypsinotus* and *P. platyceros* by recreational visitors and commercial fishermen, continues presently (personal observations 1980). The shallow sill reduces opportunities for recruitment of shrimps from outside populations, and shrimps within the upper bay may grow slowly due to cold temperatures and food limitation. Thus, the populations in the upper bay are probably slow to recover from over-fishing.

The abundance of surface-feeding birds and seals in tidewater-glacier fjords seems to be related to the high suspended sediment load and presence of icebergs. The presence of crustaceans (copepods, euphausiids, and pandalid shrimps) near the surface of the turbid water attracts surface-feeding birds. Ice calved off the glacier face, and subglacial meltwater streams, cause turbulence which brings euphausiids and shrimps to the surface. Icebergs are used by harbor seals for pupping and resting. Therefore, during the pupping and molting seasons, seals are abundant on glacial icebergs in the fjords. Pandalid shrimps may also serve as a food source, particularly for young seals.

The combination of a high suspended sediment load, shallow sill, and the presence of icebergs within a tidewater-glacier fjord results in a unique ecosystem. Although the presence of large marine mammal and bird populations at the head of fjords suggests high productivity, pelagic and benthic organisms are not necessarily abundant there. The stocks of pandalid shrimps in tidewater-glacier fjords are probably not a sustainable resource, but more likely represent populations of slow-growing individuals vulnerable to over-fishing.

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DATA APPENDIX

Table A-1. Density (no./m²) of zooplankton taxa collected by vertical net tow.

Station	AB 1	AB 1	AB 1	AB 4	AB 4	AB 9
Depth	30 m	50 m	38 m	150 m	186 m	187 m
Mesh size	216 μ	216 μ	202 μ	216 μ	202 μ	216 μ
Date of tow	6-16-80	7-22-80	12-4-79	6-18-80	12-4-79	6-15-80
Species						
Coryne tubulosa		5.1				5.1
Aglantha digitale	43.4	30.6		96.9		20.4
Polychaete larvae				510		
Gastropoda:snail	1276	2040		510		
Gastropoda:pteropod	2.6			1020[a]		
Cyphonautes larvae			6620		21,400	
Ostracoda				510[b]	510	
harpacticoid copepod				510		
Oithona similis	81,630	31,100	6240	169,400	17,300	130,000
O. spinirostris				1020		
Oncaea sp.		6620	1910	47,960	18,900	8150
Acartia longiremis	46,940	3060	637	19,900		2040
A. tumida	255					
Pseudocalanus sp.	326,500	221,000	24,600[x]	517,300	37,200	465,000
Microcalanus sp.		510		1531		
Metridia lucens	1536	1020		12,245	5100	34,600
M. okhotensis				4082	5100	6110[+]

Table A-1 (continued).

Station	AB 1	AB 1
Depth	30 m	50 m
Mesh size	216 μ	216 μ
Date of tow	6-16-80	7-22-80
Species		
Calanus plumchrus	81.6	
C. glacialis		
C. marshallae	25.5	510
C. cristatus		
Euchaeta elongata		
Centropages abdominalis	1531	
Copepod sp.		3060
Nauplius larvae	12,245	
Mysidacea		
Cyphocaris challengeri		
Primo macropa		
Parathemisto libelula		
Scolecithricella sp.		
Amphipoda		
Euphausia pacifica		35.7
Thysanoessa inermis		
T. longipes		

AB 1 38 m 202 μ 12-4-79	AB 4 150 m 216 μ 6-18-80	AB 4 186 m 202 μ 12-4-79	AB 9 187 m 216 μ 6-15-80
	2040	1530	2040
			2040
255		2040	2040
	5.1		
	5.1		
	510		
2550			
	6122		
2.5	40.8	20.4#	
	51.0		
	20.4		
	10.2		
	5.1		
		19.1	
		8.9	
		2.5	

Table A-1 (continued).

Station	AB 1	AB 1	AB 1
Depth	30 m	50 m	38 m
Mesh size	216 μ	216 μ	202 μ
Date of tow	6-16-80	7-22-80	12-4-79
Species			
T. raschii		5.1	
euphausiid larvae	10.2	71.3	
hyppolytid larvae	5.1		
crangonid larvae	2.6	15.3	
crab larvae		15.3	
Sagitta elegans	699	1100	194*
Oikopleura sp.	10.2		
Teleosteii larvae		25.5	

[a] *Limacina* sp.

[b] *Conchoecia*

[x] early stage

+*Metridia* sp.

#*Meterythrops robusta*

*unidentified chaetognath

AB 4 150 m 216 μ 6-18-80	AB 4 186 m 202 μ 12-4-79	AB 9 187 m 216 μ 6-15-80
112	510	423
		2040

Table A-2. Distribution of zooplankton biomass (dry weight) collected by vertical net tows from selected depths at stations AB 6 and AB 4, July 22, 1980. Net mesh = 216μ.

Depth of tow	Total dry weight of zooplankton ($grams/m^2$)	Depth interval	Dry weight of zooplankton between depths ($grams/m^2$)
Station AB 6			
25 m	1.40	0-25 m	1.40
50 m	2.77	25-50 m	1.37
75 m	4.36	50-75 m	1.59
Station AB 4			
25 m	0.35	0-25 m	0.35
50 m	0.99	25-50 m	0.64
100 m	1.56	50-100 m	0.57
150 m	4.00	100-150 m	2.44

Table A-3. Organisms collected by midwater trawl in Aialik Bay.

Station: AB 4
Start: 59°53.1'N 149°41.5'W
Turn: 59°54.5'N 149°41.2'W
End: 59°53.0'N 149°41.5'W
Date: 12-3-80
Depth: 50 meters (?), 180 m bottom depth
Time: 0315-0400
Distance: 5.4 km
Gear: Isaacs-Kidd trawl (1.8 m)

Taxa	Total count	No./km fished	Remarks
Arthropoda			
Crustacea			
Parathemisto libellula	14	2.6	
Primno macropa	2	0.37	
Euphausia pacifica	39	7.2	
Thysanoessa inermis	29	5.4	
Thysanoessa rachii	12	2.2	
Thysanoessa longipes	13	2.4	
Thysanoessa spinifera	11	2.0	
Neomysis rayii	8	1.5	
Pasiphaea pacifica	17	3.2	
Pandalus borealis	27	5.0	2 female, 25 male, $\bar{x}$=17.4mm
Pandalus goniurus	8	1.5	1 we, 7 male, $\bar{x}$=16.6mm
Chordata			
Teleosteii			
Theragra chalcogramma	4	0.74	
Mallotus villosus	1	0.19	
Thaleichthys pacificus	1	0.19	
Clupea harengus pallasi	1	0.19	
Teleosteii larvae	95	17.6	

we=with eggs

Table A-4. All organisms identified from van Veen grab collections in Aialik Bay, December 3, 1980 and November 11, 1981 listed by station and date of collection. Organisms from station AB 6 were collected by one pipe dredge and one Ekman dredge sample.

Station	AB 9		AB 4		AB 8	AB 5		AB 6
Date	'80	'81	'80	'81	'81	'80	'81	'81
Foraminifera						X	X	
Stylatula gracile	X	X						
unknown Rhynchocoela	X	X	X					
Cerebratulus sp.							X	
Polynoidae							X	
Anaitides sp.	X			X				
Nephtys sp.				X	X	X#	X	
Nephtys cornuta	X	X	X	X	X			
Nephtys punctata	X	X	X	X	X	X	X	X
Glycera capitata	X			X				
Goniada annulata	X	X						
Onuphis iridescens	X	X						
Lumbrineris sp.	X	X	X	X	X		X	X
Ninoe sp.	X	X						
Paraonidae				X				
Tauberia gracilis	X	X						
Polydora sp.			X	X	X		X	X
Prionospio sp.				X	X		X	
Spio sp.	X							
Pygiospio sp.				X				
Spiochaetopterus sp.	X	X						
Cirratulidae		X#	X#					
Tharyx sp.		X	X	X	X		X	X
Scalibregma inflatum				X				
Ophelina acuminata			X					
Sternaspis scutata	X	X						
Capitellidae						X#	X#	
Heteromastus filiformis	X	X	X	X	X	X	X	X
Maldane glebifex			X	X	X		X	
Maldanidae		X			X			
Praxillella sp.	X							
Praxillella gracilis	X	X						
Rhodine sp. fragments	X	X						
Myriochele heeri	X				X	X	X	
Myriochele occulata	X	X		X	X		X	
Pectinaria sp.	X							
Ampharetidae			X#	X	X#	X#	X#	X
Ampharete sp.	X	X						
Ampharete finmarchica					X		X	
Lysippe labiata			X		X	X	X	

Table A-4 (continued).

Station	AB 9		AB 4		AB 8	AB 5		AB 6
Date	'80	'81	'80	'81	'81	'80	'81	'81
Melinna cristata	X		X	X	X	X	X	X
Artacama conifera			X					
Terebellides stroemii	X	X		X	X	X		
Trochochaeta multisetosa			X		X	X	X	
Hirudinea							X	
Chaetoderma robusta	X	X	X	X	X	X	X	
Pelecypoda				X				
Nucula tenuis	X	X	X	X	X			
Nuculana sp.	X	X	X	X	X	X	X	X
Yoldia sp.	X							
Yoldia thraciaeformis		X						
Axinopsida sp.						X#		
Axinopsida serricata		X	X	X		X	X	X
Axinopsida viridis			X	X	X	X	X	X
Odontogena borealis	X	X						
Clinocardium sp.			X					
Macoma sp.			X		X			
Pandora grandis		X						
Cardiomya sp.		X						
Cardiomya planetica	X							
Solariella sp.	X	X						
Turridae	X		X	X				X
Cylichna sp.				X	X			
Dentalium sp.	X	X		X				
Ostracoda	X	X						
**Euchaeta elongata*			X					
**Meterythrops robusta*				X				
Eudorella emarginata	X	X	X	X			X	X
*Lysianassidae					X			
**Parathemisto pacifica*				X				
*Euphausiacea						X		
**Thysanoessa inermis*								X
**Thysanoessa longipes*			X					
**Pandalus borealis*								X
*Pandalidae							X	
*Insecta			X					
Terebratulina unguicula	X							
Brisaster townsendi	X	X						
Ophiuridae	X							

*non-benthic taxa, not used for diversity indices or biomass
#other categories not used for diversity indices or biomass

Table A-5. Benthic organisms identified from a single van Veen grab at each station on December 4, 1979 in Aialik Bay.

Station AB 1, 38 m depth

Polychaeta:	
Nephtys sp.	1
Magelona sp.	2
Capitellidae	1
Macoma sp.	1

Station AB 2, 40 m depth

Polychaeta:	
Nephtys sp.	10
Melinna cristata	23
Cirratulidae	1
Lumbrineris sp.	3
Myriochele occulata	1
Spionidae	1
Trochochaeta multisetosum	1
Glyceridae	1
Arthropoda:	
Eualus avina	1
Balanus sp.	1
Mollusca:	
Nuoulana sp.	3

Station AB 4, 186 m depth

Polychaeta:	
Nephtys sp.	5
Cirratulidae	4
Spionidae	1
Maldanidae	1
Arthropoda:	
Amphipoda	1
Mollusca:	
Nuoulana sp.	2
unknown worm	1

Table A-6. Organisms collected by otter trawl in Aialik Bay. Remarks: we=with eggs and wo=without eggs, color refers to color of eggs, length measurements are carapace length for shrimps and total length for fishes.

Trawl 1.
Station: AB 3 - AB 4
Start: 59°54.7 N 149°42.4 W
End: 59°53.0 N 149°42.3 W
Date: 12-4-79
Depth: 140 m
Time: 1504-1548
Distance: 2.9 km
Gear: Small otter trawl (4 m)

Taxa	Total count	No./km fished	Remarks
Mollusca			
Nuculana sp.	198	68.3	
Clinocardium sp.	15	5.2	
Serripes groenlandicus	1	0.34	
Unidentified bivalve	1	0.34	
Arthropoda			
Crustacea			
Pandalus borealis	782	269.7	190 we, 592 wo
Pandalus goniurus	447	154.1	296 we, 151 wo
Pandalus hypsinotus	11	3.8	3 we, 8 wo
Pandalus platyceros	1	0.34	
Pandalopsis dispar	116	40.0	18 we, 98 wo
Crangon communis	122	42.1	38 we, 84 wo
shrimp fragments			
Chionocetes bairdi	1	0.34	
Labidochirus splendescens	2	0.69	
Pagurus aleuticus	1	0.34	
Natica clausa	2	0.69	
Chordata			
Teleosteii			
Theragra chalcogramma	4	1.38	#
Lumpenella longirostris	1	0.34	21.5 cm

#*T. chalcogramma*: 9.5, 11.0, 11.5, 11.5 cm

Table A-6 (continued).

Trawl 2
Station: AB 5/AB 8
Start: 59°56.1 N 149°41.9 W
End: 59°54.0 N 149°40.4 W
Date: 6-11-80
Depth: 80-96 m
Time: 2030
Distance: 4.5 km
Gear: Small otter trawl

Taxa	Total count	No./km fished	Remarks
Cnidaria			
Anemone	1	0.22	
Mollusca			
Clinocardium sp.	20	4.4	
Octopus sp.	2	0.44	
Arthropoda			
Crustacea			
Pandalus borealis	300	66.7	
Pandalus goniurus	60	13.3	
Pandalus hypsinotus	80	17.8	
Pandalopsis dispar	20	4.4	
Paguroidea	2	0.44	
Chionocetes bairdi	3	0.67	
Crangon sp	?	?	
Hippolytidae	?	?	
Echinodermata			
Asteroidea A	?	?	
Asteroidea B	?	?	
Chordata			
Teleosteii			
Lumpenus maculatus	10	2.2	
Theragra chalcogramma	13	2.9	#
Lumpenella longirostris	2	0.44	
Limanda aspera	1	0.22	19.4 cm
Hippoglossoides elassodon	4	0.89	*
Mallotus villosus	1	0.22	11.4 cm

#*T. chalcogramma*: 9.3, 11.2, 11.3, 11.4, 11.8, 12.0, 12.0, 12.5, 12.6, 12.7, 12.9, 15.2, 19.4 cm

**H. elassodon*: 10.7, 10.8, 13.3, 20.0 cm

Table A-6 (continued).

Trawl 3
Station: AB 4-AB 5
Start: 59°53.1 N 149°41.5 W
End: 59°56.3 N 149°41.9 W
Date: 12-3-80
Depth: 192 m
Time: 0540-0700
Distance: 5.9 km
Gear: Small otter trawl

Taxa	Total count	No./km fished	Remarks
Cnidaria			
Anemone	11	1.86	
Polychaeta			
Melinna cristata	1	0.17	
Polydora sp.	3	0.51	
Mollusca			
Clinocardium sp.	3	0.51	
Nuculana sp.	63	10.7	
Arthropoda			
Crustacea			
Pandalus borealis	221	37.5	9 we, bright blue*
Pandalus hypsinotus	1	0.17	
Pandalopsis dispar	12	2.0	6 we, bright blue
Lebbeus groenlandicus	1	0.17	
Eualus biunguis	3	0.51	
Eualus avinus	3	0.51	
Spirontocaris arcuata	2	0.34	
Crangon communis	2	0.34	
Pagurus aleuticus	1	0.17	
Chordata			
Teleosteii			
Lumpenella longirostris	11	1.9	#
Cottidae	5	0.85	@

**P. borealis*: ♂$\bar{x}$=17.8, ♀$\bar{x}$=20.3, ♀we $\bar{x}$=19.3, all sexes $\bar{x}$=18.7 mm
#*L. longirostris*: 16.9, 17.3, 17.4, 17.9, 18.5, 19.0, 20.1, 20.2, 20.4, 22.6, 23.0 cm
@Cottidae: 4.4, 4.5, 4.5, 4.6, 4.6 cm

Table A-6 (continued).

Trawl 4
Station: AB 5-AB 8
Start: 59°56.3 N 149°49.9 W
End: 59°54.3 N 149°41.6 W
Date: 12-3-80
Depth: 140 m
Time: 0710-0800
Distance: 3.85 km
Gear: Small otter trawl

Taxa	Total count	No./km fished	Remarks
Cnidaria			
Anemone	1	0.26	
Polychaeta			
Nephtys sp.	1	0.26	
Melinna cristata	2	0.52	
Maldane sp.	1	0.26	
Ampharete sp.	1	0.26	
Lysippe labiata	1	0.26	
Spionidae	1	0.26	
Mollusca			
Nuculana sp.	55	14.4	
Clinocardium sp.	2	0.52	
Macoma sp.	1	0.26	
Arthropoda			
Crustacea			
Pandalus borealis	2008	521.6	148 we
Pandalus goniurus	26	6.8	3 we
Pandalus hypsinotus	17	4.4	3 we
Pandalopsis dispar	65	16.9	23 we
Lebbeus sp.	1	0.26	
Eualus biunguis	5	1.3	
Eualus avinus	61	15.8	
Eualus suckleyi	7	1.8	1 we
Crangon communis	67	17.4	
Chionocetes bairdi	3	0.78	2 we, dark orange
Chordata			
Teleosteii			
Lumpenella longirostris	19	4.9	
Cottidae	3	0.78	4.6, 4.8, 14.2 cm
Hippoglossoides elassodon	1	0.26	19.3 cm
Theragra chalcogramma	4	1.0	10.1, 10.6, 23.8, 24.9 cm
Thaleichthys pacificus	1	0.26	14.2 cm
Lycodes sp.	2	0.52	13.6, 14.8 cm

Table A-7. Number and species of pandalid shrimps collected by vertically suspended shrimp pots in Aialik Bay during the summers of 1980 and 1981. This data was used for species, number, and sex distributions. PB=*Pandalus borealis*, PG=*P. goniurus*, PH=*P. hypsinotus*, PP=*P. platyceros*. Two numbers (1/4) indicates the number of shrimp collected in two separate pots at the same depth and time interval.

Station AB 4, July 4-5, 1980

Time interval	Depth of pot: 3 m	49 m	95 m	140 m	186 m
6-11 am	0	220 PB	158 PB 1 PG	17 PB	5 PH 1 PP
11 am-5 pm	0	211 PB	378 PB 1 PG	44 PB	7 PB 13 PH
5-11 pm	70 PB	246 PB	376 PB	33 PB	5 PB 10 PH
11 pm-6 am	24 PB 6 PG	263 PB 2 PG	69 PB	119 PB 1 PG	8 PB 9 PH

Station AB 6, July 14-15, 1980

Time interval	Depth of pot: 3 m	29 m	55 m	81 m	107 m
6-10 am	0	142 PB 2 PG	76 PB	41 PB	3 PB 3 PH
10 am-2 pm	0	140 PB 11 PG	42 PB	39 PB	8 PB
2-6 pm	0	162 PB 28 PG	80 PB	58 PB	12 PB
6-10 pm	0	109 PB 5 PG	83 PB	32 PB	21 PB
10 pm-6 am	17 PB 5 PG	74 PB	177 PB	117 PB	1 PB 19 PH

Table A-7 (continued).

Station AB 6, July 20-21, 1980

Time interval	Depth of pot 3 m	29 m	55 m	81 m	107 m
6-10 am	0	112 PB 11 PG	53 PB 2 PG	15 PB	9 PB 1 PH
10 am-2 pm	0	95 PB 15 PG	114 PB	49 PB 1 PG	10 PB 12 PH 1 PP
2-6 pm	0	60 PB 3 PG	41 PB	63 PB	3 PB 1 PH
6-10 pm	0	82 PB 6 PG	70 PB	36 PB	4 PB
10 pm-6 am	0	41 PB 2 PG	111 PB	152 PB 1 PG	1 PB 5 PH

Station AB 6

Time interval	Depth of pot 3 m	29 m	55 m	81 m	107 m
June 5, 1981 6-10 am	0	0	27 PB 2 PG	72/109 PB	2/0 PB
May 26, 1981 10 am-2 pm	0/0	1/1 PG	91/24 PB 22/10 PG	32/18 PB 1/1 PG	4/5 PB 0/1 PG
3-7 pm	0/0	0/6 PB 0/18 PG	41/12 PB 21/8 PG	15/5 PB 1/0 PG	3/1 PB
June 9-10, 1981 6-10 pm	0	0	1 PG	37 PB	16 PB 2 PG 2 PH
10 pm-5 am	4 PB 9 PG	2 PB 8 PG	48 PB 5 PG	8/37 PB	21/4 PB 1 PG